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Experimental investigation of temperature and velocity distribution about a rocket jet

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EXPERIMENTAL INVESTIGATION OF TEMPERATURE AND VELOCITY DISTRIBUTION ABOUT A ROCKET JET

Thesis by

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EXPERIMENTAL INVESTIGATION OF TEMPERATURE AND VELOCITY DISTRIBUTION ABOUT A ROCKET JET

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In Partial Fulfillment of the
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in Aeronautical Engineering

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SUMMARY

The purpose of the investigation was to determine the temperature distribution and velocity profile surrounding the wake of a 1500 pound thrust liquid rocket motor. The temperature measurements were restricted to those 500°F and below. The velocities measured were in the region in which the temperature measurements were made.

The region in which the temperatures exceeded 500°F was found to be included within a solid angle of ten degrees. The high temperature region was found to be larger than the high velocity region.

The investigation was carried out during the academic year 1946-1947 at GALCIT Jet Propulsion Laboratory under the supervision of Dr. Robert H. Boden.

INTRODUCTION

The jet of gases from a de Laval nozzle has been extensively studied by a number of investigators. These studies were primarily limited to the shock wave characteristics in the supersonic flow. Optical methods have been developed to show the variation of density in the jet. However, little experimental work has been done to determine the velocity, pressure, and temperature in the jet and in the regions surrounding the high velocity gases.

The object of this investigation was to measure the velocity and temperature distribution in the region surrounding the high velocity luminous gases.

The measurements were carried out at GALCIT in the Jet Propulsion Laboratory during the academic year 1946-47 under the supervision of Dr. Robert Boden.

EQUIPMENT

The liquid rockets which were run for performance data with various fuel specifications were of the regeneratively cooled type developing a 1500 pound thrust. The rocket motors were all mounted on the same thrust carriage and the structure of the pit surrounding the rockets remained essentially the same for all of the runs. The rocket motors were mounted horizontally as shown in Fig. 1. Figs. 1 and 2 show the irregular nature of the area into which the rocket was fired.

The radiation thermocouples which were used to make the temperature survey were of the iron-constantan type. Instructions and a schematic drawing of the type used may be found in Fig. 3. The thermocouples were used in connection with a Brown Potentiometer which had 15 outlets. The potentiometer could record the 15 different temperatures at a rate of one a second if the temperature at each thermocouple were constant. Fig. 5 is a photograph of this Brown Potentiometer. A rack made of pipe and angle iron was built to hold the thermocouples in position as shown in Fig. 5.

To reduce the effect of radiation, a shield was built to protect a thermocouple from the flame of hot gases. Fig. 6 is a schematic representation of the shield used to produce this effect.

A Leeds and Northrop portable optical Pyrometer, No. 8622, was used to determine the flame temperature of the luminous flame. The circuit of this pyrometer appears in Fig. 7.

A stagnation temperature probe which doubled as a shielded thermocouple was mounted on the rack as shown in Fig. 5. Fig. 8 is a photostatic copy of the production drawing for the stagnation probe.

The Prandtl Pitot tube was selected as best suited for the velocity survey because of its yaw characteristics as shown in Fig. 9. Fig. 10a and Fig. 10b are copies of the production drawings for the Prandtl tube. Because of the high temperatures to which the tubes were to be subjected, the joints were all silver soldered. The Pitot tubes were mounted upon the thermocouple rack six inches apart, (Fig. 5). One-quarter inch copper tubing was used to connect the Pitot tubes with the tubes of the multiple manometer board.

The multiple manometer board (Fig. 11) consisted of 12 "U" tubes half filled with alcohol. The alcohol was dyed red to improve its photographic characteristics. The board was mounted upon a frame of angle iron which could be bolted in three tilting positions (90°, 30°, and 14.5°). To record the manometer tube displacements, a 35 mm. movie camera was mounted on the manometer frame. Two reflector type photo flood lamps, mounted as shown in Fig. 11, provided the illumination.

To measure the velocities close to the motor within the firing pit, a remote control variable position Prandtl tube was built (Fig. 12). A small synchro was placed inside of a metal box with a shaft protruding through the top to which the Prandtl tube was mounted (Fig. 13). The control synchro and power source for the variable position Pitot tube can be seen in Fig. 14. This control station was inside the observation room of the pit. Fig. 15 is the electrical circuit for the control of the variable position Pitot. The pressures

from this remote controlled Pitot tube were measured with the small inclined manometer, Fig. 16.

The luminous portion of the jet was photographed with an Eastman high speed 16 mm. movie camera. The camera was capable of taking 3,000 frames a second and was run at top speed for these photographs. Two portions of the flame were studied; (1) the region just aft of the nozzle; (2) the region in which the luminous flame ends.

PROCEDURE

The rocket motors were run primarily for performance information. The temperature and velocity survey of this report was added after the performance series had been started.

(1) An initial survey to determine the suitability of an iron-constantan thermocouple was made during test runs Nos. 18, 19, 20, 21, 22, 24, 25, 26, 27 and 29. The lag in temperature response was measured during these runs.

(2) An attempt was made to protect the thermocouple from the direct radiation of the flame and to determine the effectiveness of a shield during run Nos. 28, 29, 30, 31, 32, 33, 34, and 35.

(3) A Prandtl Pitot-static tube was placed in the field to determine the possibility of using that tube for the velocity survey during runs Nos. 37 and 38.

The initial runs demonstrated that the instruments selected could be used to obtain the objectives. A rack was made upon which 11 thermocouples and 12 Pitot tubes were mounted. The Brown Potentiometer was available in the pit and the inclined manometer board was built so that velocities over a wide range could be determined.

The rack was placed perpendicular to the longitudinal axis of the motor at five stations behind the motor. The five stations were 26.5, 24.5, 22, 19 and 16 feet aft of the motor nozzle. The rack was so oriented for runs 73 to 93 inclusive. For runs 95 to 98 the rack was placed at a 37° angle so that the direction of the velocity could be determined. The temperature survey within six feet of the motor

was completed by placing the rack parallel with the longitudinal axis of the motor during runs 99 and 100.

The stagnation temperature was determined by placing the stagnation probe on the rack for runs 95 to 98 inclusive.

The remote control Pitot tube was placed inside the pit close to the motor to measure the velocity profile there during runs 84 to 98 inclusive.

The investigation was extended to the flame characteristics with the use of the Leeds and Northrop Optical Pyrometer and an Eastman high speed movie camera. The optical pyrometer was held 10 feet aft of the motor and 10 feet from the axis of the flame. From this position the pyrometer was sighted upon the flame six feet aft of the nozzle. The high speed camera was set up to take kodachrome pictures of the exit of the motor during run No. 84. Black and white pictures of the end of the flame were taken during run No. 85. The camera was 10 feet from the flame during run No.84 and 45 feet from the flame during run No. 85.

RESULTS AND DISCUSSION

(1) A blackened thermocouple when exposed to a high temperature requires time to reach that temperature. Fig. 16 is the response of the thermocouples which were used in this investigation. The data for this curve was obtained from runs Nos. 19 to 23 as shown in Table I(a) to I(j). It was realized that the response of the thermocouple was faster when the change in temperature was small compared with the ambient air temperature.

(2) The shield about the thermocouple reduced the temperature rise and also produced a much slower temperature rise as is indicated in Fig. 18.

(3) The temperature surveys taken 26.5, 24.5, 22, 19 and 16 feet aft of the motor are plotted, Figs. 19a to 23a and 24a and b, as temperature rise versus radial distance from the center line of the axis of the flame. The rise in temperature was in each case corrected for time lag by the use of the thermocouple Response Curve, Fig. 17. The data is quite consistant considering the variations caused by winds and that the mixture ratio was seldom repeated. However, the temperatures measured by the thermocouples are not necessarily the air temperatures, since the air is relatively transparent to radiation. The thermocouples reached equilibrium after sixty seconds which indicates that they were losing as much energy via conduction along the leads, convection to the air, and the radiation losses as they were receiving via radiation. Some of the temperatures were taken in the mixing region of the jet gases and ambient air. The location of this mixing region was not determined in this investigation.

(4) The flame temperatures, six feet aft of the nozzle as measured by the optical pyrometer, were 33[illegible] C°F, 3260°F, and 3300°F. These temperatures are approximately 600° above the theoretical exit temperatures. This may be explained by the after burning of the exhaust gases. The emissivity of the flame was taken to be unity because it consists mainly of flowing carbon particles. The pyrometer was hand held at a distance of ten feet aft of the motor and ten feet from the center line of the exhaust flame. A slight burning sensation was felt by the observer on the face and arms which were exposed to the flame.

(5) The velocity measurements were made with the assumption that the flow was parallel with the ground at the level of the motor. This assumption was not checked and may have been erroneous. The velocity versus distance from the center line of the exhaust jet may be found in Figs. 19b to 23b. A plot of the velocity profile showing direction velocity and streamlines may be seen in Figs. 25 and 27.

(6) The characteristic of the first shock wave aft of the motor in the jet was recorded on a Kodachrome film by the Eastman high speed camera during run No. 84. It was not possible to measure the velocity of the exhaust gases from this film. A higher speed camera with a larger field is necessary. The average velocity of the end of the luminous gases which was measured from the black and white film taken during run No. 85, was determined to be 2300 ft/sec. Since the flow was subsonic at this distance from the motor, this would require an exhaust temperature of 2110°F at least, if the [illegible] of the gases was 1.2. The velocity was therefore considered to be a reasonable one.

CONCLUSIONS AND RECOMMENDATIONS

(1) The temperatures surrounding the jet of a 1500 pound thrust liquid rocket, as measured by a blackened thermocouple, are surprisingly low. The high temperature region gradually expands as the distance aft of the motor is increased. At 26.5 feet aft of the motor, the temperature can be expected to be 500°F higher than ambient at a distance of 25 inches from the center line of the motor. At a distance of four feet aft of the nozzle, the temperature rise can be expected to be 500° when only 12 inches from the center line of the flame. However, a considerable amount of heat is conducted away by the thermocouple leads. Therefore, before placing equipment as closely as these temperatures indicate as safe, it would be necessary to determine the heat losses of the equipment to be expected from conduction, radiation, and convection.

(2) The velocity survey was rather sketchy, but does show that the induced velocities are quite small and of the order of 50 ft/sec. The velocities were appreciable (over 100 ft/sec.) in the region in which mixing was expected. It was found that the high temperature regions were larger than the high velocity region, as was found by other investigators dealing with small hot jets.

The induced velocities might be successfully measured with the use of small smoke sources placed throughout the region of interest and the paths of the smoke recorded by a movie camera. A rack of Pitot tubes could be made so that each tube could be pivoted during the run. This could be accomplished very nicely by electrical or mechanical linkages.

The survey should be extended to include the luminous region of the exhaust gases. A spectogram of the flame would be desirable. The optical pyrometer could be successfully employed to determine the flame temperatures if the emissivity of the flame were determined.

The ultra-high speed camera may be the best method to determine the velocities of the hot exhaust gases.

TABLE Ia

TEMPERATURE SURVEY

Run #18 Duration of Run 45.8 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 1.35

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 21"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	52	0	52
6	86	7	132
37	106	38	152
53	82	54	122
70	74	71	109

TABLE Ib

TEMPERATURE SURVEY

Run #19 Duration of Run 59.6 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 1.26

Thermocouple #2		Thermocouple # 3	
Dist. aft of Motor 48"		Dist. aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 15"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	53	0	53
14	74	15	142
35	82	37	166
58	85	59	169

TABLE Ic

TEMPERATURE SURVEY

Run #20 Duration of Run 45 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 1.96

Thermocouple #2		Thermocouple #3	
Dist. aft of Motor 48"		Dist. aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 12"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	56	0	56
30	69	6	386
		33	426

TABLE Id

TEMPERATURE SURVEY

Run #21 Duration of Run 44.9 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 1.91

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 12"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	57	0	57
18	70	30	494

TABLE I(f)

TEMPERATURE SURVEY

Run #23 Duration of Run 45 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 2.30

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 12"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	55	0	56
15	87	16	226
40	93	42	240

8104

TABLE I(g)

TEMPERATURE SURVEY

Run #24 Duration of Run 45.1 sec. Motor M-272

Fuel FUOH Oxidizer WFNA Mixture Ratio 2.30

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 120"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 30"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	73	0	74
12	91	14	151
37	102	39	173

TABLE I(h)

TEMPERATURE SURVEY

Run #25 Duration of Run 45.1 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 2.26

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48" Dist. from ℄ of Motor 67"		Dist. Aft of Motor 120" Dist. from ℄ of Motor 30"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	64	0	88
1	65	2	130
31	99	32	148

TABLE I(i)

TEMPERATURE SURVEY

Run #26 Duration of Run 21 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 2.39

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 120"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 18"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	74	0	79
11	90	15	489

TABLE I(j)

TEMPERATURE SURVEY

Run #27 Duration of Run 45.1 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 2.20

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 120"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 19"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	67	0	67
30	90	35	500

TABLE I(k)

TEMPERATURE SURVEY

Run #35 Duration of Run 44.8 sec. Motor M-272

Fuel FUOH

Oxidizer 95% WFNA & 5% H_2O Mixture Ratio 2.15

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 120"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 13"	
Time Sec.	Temperature °F	Time Sec.	Temperature °F
0	66	0	74
29	96	1	266
		30	500

TABLE I(b)

TEMPERATURE SURVEY

Run #36 Duration of Run 44.8 sec. Motor M-272

Fuel FUOH

Oxidizer 95% WFNA & 5% H_2O Mixture Ratio 2.05

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 120"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 22"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	66	0	72
11	84	14	166
34	98	35	182

TABLE I(m)

TEMPERATURE SURVEY

Run #38 Duration of Run 59 sec. Motor M-272

Fuel FUOH

Oxidizer 95% WFNA & 5% H_2O Mixture Ratio 2.20

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 15"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	61	0	62
9	76	10	126
32	86	33	141
55	93	59	158

TABLE I(k)

TEMPERATURE SURVEY

Run #39 Duration of Run 45 sec. Motor M-272

Fuel FUOH

Oxidizer 95% WFNA 5% H_2O Mixture Ratio 2.32

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 15"	
Dist. from ℄ of Motor 300"		Dist. from ℄ of Motor 36"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	56	0	64
32	58	10	145
		38	169

TABLE II(a)

TEMPERATURE SURVEY

Run #28 Duration of Run 45.4 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 2.56

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 24"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	67	0	67
12	79	13	90
40	89	41	130
65	79	66	126
		82	120

TABLE II(b)

TEMPERATURE SURVEY

Run #29 Duration of Run 45 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 2.53

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 24"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	66	0	66
22	82	83	102
45	86	46	122
		110	119

TABLE II(c)

TEMPERATURE SURVEY

Run #30 Duration of Run 45.2 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 3.03

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 22"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	62	0	62
15	71	16	82
40	74	41	105
		65	104
		82	102

TABLE II(d)

TEMPERATURE SURVEY

Run #31 Duration of Run 45.2 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 3.11

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 300"	
Dist. from ℄ of Motor .67"		Dist. from ℄ of Motor 36"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	57	0	59
26	63	27	90
		57	97
		74	96

TABLE II(e)

TEMPERATURE SURVEY

Run #32 Duration of Run 45.6 sec. Motor M-272

Fuel FUOH

Oxidizer WFNA Mixture Ratio 3.10

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 22"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	64	0	64
23	75	24	86
55	73	56	105
73	70	74	102

TABLE II(f)

TEMPERATURE SURVEY

Run #33 Duration of Run 45 sec. Motor M-272

Fuel FUOH

Oxidizer 95% WFNA & 5% H_2O Mixture Ratio 3.10

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 22"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	66	0	68
13	90	14	76
38	104	39	96
62	88	63	105

TABLE II(g)

TEMPERATURE SURVEY

Run #34 Duration of Run 45 sec. Motor M-272

Fuel FUOH

Oxidizer 95% WFNA & 5% H_2O Mixture Ratio 1.73

Thermocouple #2		Thermocouple #3	
Dist. Aft of Motor 48"		Dist. Aft of Motor 48"	
Dist. from ℄ of Motor 67"		Dist. from ℄ of Motor 22"	
Time	Temperature	Time	Temperature
Sec.	°F	Sec.	°F
0	68	0	68
10	89	11	75
30	106	31	92
107	84	108	120
156	80	137	124

TABLE III a

TEMPERATURE SURVEY

Run #73 Duration of Run 45.1 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ratio 2.03 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Seconds	°F	°F	ΔT	ΔT_c
13	5	10	500	56	444	710
19	6	11	500	57	443	681
25	7	13	475	57	418	590
31	9	25	348	57	291	331
37	10	28	276	57	219	244
43	11	29	210	57	153	168
49	13	35	154	58	96	102
55	14	37	111	58	53	56
61	15	40	100	58	42	44

TABLE III b

TEMPERATURE SURVEY

Run #74 Duration of Run 45 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ratio 1.69 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
(inches)		(sec.)	(°F)	(°F)	ΔT	ΔT_c
13	5	22	500	48	452	532
19	6	23	500	49	451	525
25	7	24	460	52	408	470
31	9	39	318	47	271	282
37	10	40	282	47	235	244
43	11	50	150	46	104	105
49	13	53	104	52	52	53
55	14	54	80	54	26	26

TABLE III c

TEMPERATURE SURVEY

Run # 75 Duration of Run 45.0 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ratio 1.70 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
29	6	10	315	72	243	389
35	7	14	218	72	146	200
41	9	18	177	71	106	132
47	10	25	136	72	64	73
53	11	26	104	72	32	36
59	13	30	94	72	22	24
65	14	31	85	72	13	14
71	15	32	83	72	11	12

TABLE III d

TEMPERATURE SURVEY

Run #77 Duration of Run 44.8 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ratio 1.40 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
59	11	1	91	68	23	
67	13	6	89	68	21	47
71	14	7	84	68	16	32
77	15	8	80	68	12	22
29	6	29	426	68	358	394

TABLE III e

TEMPERATURE SURVEY

Run #78 Duration of Run 45 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ratio 1.38 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec	°F	°F	ΔT	ΔT_c
29	6	21	428	76	352	421
35	7	22	382	80	302	356
41	9	39	284	76	208	216
47	10	40	158	76	82	85.5
53	11	46	115	78	37	37.8
59	13	51	100	75	25	25.2
65	14	52	92	76	16	16
71	15	53	90	79	11	11

TABLE III f

TEMPERATURE SURVEY

Run #30 Duration of Run 45.2 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ration 2.36 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
47	10	1	127	85	42	-
59	13	9	110	82	28	46
65	14	10	102	80	22	35.2
71	15	11	96	84	12	18.5
17	3	20	480	85	395	476
23	5	40	421	85	336	350
29	6	44	346	85	261	268

TABLE III 9

TEMPERATURE SURVEY

Run 81 Duration of Run 45.2 sec. Motor M-272

Fuel 80% Aniline 20% FUOH

Oxidizer 6 1/2% RFNA

Mixture Ratio 2.36 Distance Aft of Nozzle 26.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
27	3	422	25	56	366	419
31	5	225	35	56	190	202
37	6	190	36	56	154	162
43	7	121	40	56	81	84.5
49	9	93	42	53	51	52.5
55	10	80	43	56	37	38
61	11	66	44	54	22	22.4

TABLE IV a

TEMPERATURE SURVEY

Run #32 Duration of Run 40 sec. Motor M-293

Fuel 80% Aniline 20% FUOH

Oxidizer WFNA

Mixture Ratio 1.75 Distance Aft of Nozzle 24.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
41	3	9	248	72	100	352
47	5	10	172	72	62	167
53	6	11	134	72	35	100
59	7	14	106	71	20	54
65	9	15	92	72	10	28
71	10	16	82	72	6	13
77	11	18	78	72	5	8
83	13	19	77	72	2	6
89	14	20	74	72	3	3
95	15	31	74	71	142	4

TABLE IV b

TEMPERATURE SURVEY

Run #83 Duration of Run 45.3 sec. Motor M-293

Fuel FUQH

Oxidizer WFNA

Mixture Ratio 1.77 Distance Aft of Nozzle 24.5 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
41	3	15	226	63	163	218
47	5	23	187	64	123	143
53	6	26	132	58	74	83.5
59	7	33	102	62	40	43
65	9	38	70	55	15	16
71	10	39	69	62	7	7
77	11	40	67	62	5	5
83	13	42	67	62	5	5
89	14	43	66	63	3	3
95	15	44	64	62	2	2

TABLE V a

TEMPERATURE SURVEY

Run #85 Duration of Run 49.9 sec. Motor M-293

Fuel FUOH

Oxidizer WFNA

Mixture Ratio 2.22 Distance Aft of Motor 22 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
41	3	11	134	60	74	114
47	5	13	116	68	47	67
53	6	19	84	68	16	30
59	7	20	74	68	6	7
65	9	25	73	68	5	6
71	10	26	70	68	2	2
77	11	27	69	68	1	1
83	13	30	69	66	3	3
89	14	31	66	64	2	2
95	15	32	69	66	3	3

TABLE V b

TEMPERATURE SURVEY

Run #87 Duration of Run 45 sec. Motor M-293

Fuel FUOH

Oxidizer WFNA

Mixture Ratio 2.46 Distance Aft of Nozzle 22 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
36	5	14	142	58	84	116
42	6	16	100	58	42	55
48	7	18	80	58	22	28
54	9	21	72	58	14	17
60	10	23	65	58	7	8
66	11	24	63	58	5	6
72	13	28	63	58	5	6
78	14	29	62	58	4	4
84	15	30	62	58	4	4
	2	36	136	58	78	82
30	3	38	188	58	130	135

TABLE V_c

TEMPERATURE SURVEY

Run #88 Duration of Run 44.8 sec. Motor M-293

Fuel FUOH

Oxidizer WFNA

Mixture Ratio 2.22 Distance Aft of Nozzle 22 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
	2	21	150	68	82	99
30	3	27	201	72	129	145
36	5	28	155	72	83	92
42	6	29	122	72	50	55
48	7	30	106	72	34	37
54	9	32	93	72	21	23
60	10	33	82	72	10	11
66	11	34	78	72	6	6
72	13	39	78	72	6	6
78	14	40	76	72	4	4
84	15	41	76	72	4	4

TABLE V d

TEMPERATURE SURVEY

Run - 98 Duration of Run 45.6 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 2.40 Distance Aft of Motor 22 ft.

Distance from of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
36	5	17	280	76	204	262
41	6	26	221	76	145	163
46	7	27	186	76	110	123
51	9	31	136	76	60	65
56	10	32	116	76	40	43
60	11	33	101	76	25	27
65	13	40	90	76	14	15
70	14	41	80	74	6	6
75	15	42	78	76	2	2

TABLE VI a

TEMPERATURE SURVEY

Run #89 Duration of Run 44.3 sec. Motor M-293

Fuel FUOH

Oxidizer WFNA

Mixture Ratio 1.74 Distance Aft of Nozzle 19 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		Sec.	°F	°F	ΔT	ΔT_c
30	3	18	270	84	186	236
36	5	21	191	85	106	128
42	6	22	144	85	59	70
48	7	23	114	85	29	34
54	9	26	94	84	10	11
60	10	28	88	84	4	4
66	11	29	86	84	2	2
72	13	30	86	84	2	2
78	14	31	85	84	1	1
84	15	32	83	83	0	0

TABLE VI b

TEMPERATURE SURVEY

Run #90 Duration of Run 45.2 sec. Motor M-293

Fuel FUOH

Oxidizer

Mixture Ratio 1.73 Distance Aft of Nozzle 19 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
30	3	15	277	73	204	267
36	5	17	200	73	127	163
42	6	20	134	73	61	73
48	7	22	92	72	20	24
54	9	25	84	72	12	14
60	10	26	83	72	11	12
66	11	27	82	73	9	10
72	13	29	81	72	9	10
78	14	30	81	72	9	10
84	15	31	80	72	8	9
	2	39	236	64	172	179

TABLE VI c

TEMPERATURE SURVEY

Run 91 Duration of Run 45 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA 10% H_2O

Mixture Ratio 2.01 Distance Aft of Nozzle 19 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
*18	2	21	97	72	22	26
30	3	23	230	77	153	178
36	5	26	158	77	81	91
42	6	30	109	77	32	35
48	7	31	90	77	13	14
54	9	33	87	77	10	11
60	10	34	87	77	10	11
66	11	36	87	77	10	11
72	13	40	86	76	10	10
78	14	41	86	76	10	10
84	15	42	86	76	10	10

*Distance aft of Motor 4 in.

TABLE VI d

TEMPERATURE SURVEY

Run #97 Duration of Run 44.6 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% N_2O

Mixture Ratio 2.19 Distance Aft of Motor 19 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
33	5	30	285	88	197	216
38	6	32	217	88	129	139
43	7	34	155	87	68	72
48	9	36	121	86	35	37
53	10	37	97	86	11	12
57	11	39	91	86	5	5
62	13	41	87	86	1	1

TABLE VII a

TEMPERATURE SURVEY

Run #92 Duration of Run 45 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 2.20 Distance Aft of Motor 16 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
30	3	28	256	90	166	185
36	5	32	186	89	97	104
42	6	34	122	91	31	33
48	7	35	98	89	9	9
54	9	39	94	88	6	6
60	10	40	93	89	4	4
66	11	41	93	89	4	4
72	13	42	92	88	4	4
78	14	43	92	88	4	4
84	15	44	91	88	3	3

TABLE VII b

TEMPERATURE SURVEY

Run #93 Duration of Run 44.7 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 2.47 Distance Aft of Motor 16 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
72	13	16	96	97	-1	-1
78	14	17	96	97	-1	-1
84	15	18	96	97	-1	-1
30	3	24	215	98	117	134
36	5	28	134	98	36	40
42	6	29	105	98	7	8
48	7	30	100	98	2	2
54	9	32	99	98	1	1
60	10	33	98	98	0	0
66	11	34	98	98	0	0

TABLE VII c

TEMPERATURE SURVEY

Run 95 Duration of Run 45.4 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 1.73 Distance Aft of Motor 16 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
30	3	24	321	94	227	256
36	5	31	205	93	112	121
42	6	32	131	93	38	41
48	7	33	112	93	19	20
54	9	35	109	93	16	17
60	10	36	107	93	14	15
66	11	37	105	93	12	13
72	13	40	104	93	11	11
78	14	41	103	94	9	9
84	15	42	99	94	5	5

TABLE VII d

TEMPERATURE SURVEY

Run #96 Duration of Run 45.4 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 2.01 Distance Aft of Motor 16 ft.

Distance from ℄ of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
33	5	22	260	95	165	195
38	6	27	179	94	85	95
48	7	29	119	94	25	27
53	9	31	102	94	8	9
57	10	32	100	94	6	6
62	11	33	96	93	3	3
67	13	37	94	91	3	3
72	14	38	94	91	3	3
77	15	39	93	91	2	2

TABLE VIII a

TEMPERATURE SURVEY

Run #99 Duration of Run 45 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 1.24 Distance from ℄ 24"

Distance Aft of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
33	9	4	110	52	68	194
27	10	5	100	63	37	92
21	11	6	86	61	25	54
15	13	8	84	64	20	36
9	14	9	84	66	18	31
3	15	10	82	66	16	26
51	5	32	240	62	278	299

TABLE VIII b

TEMPERATURE SURVEY

Run #100 Duration of Run 59.9 sec. Motor M-293

Fuel FUOH

Oxidizer 90% WFNA & 10% H_2O

Mixture Ratio 2.78 Distance from ℄ of Motor 36"

Distance Aft of Motor	Thermo-couple Number	Time of Reading after Start of Run	Temp.	Temp. of Thermo-couple before Run	Temp. Rise	Temp. Rise Corrected for Thermo. Response
inches		sec.	°F	°F	ΔT	ΔT_c
61	2	50	115	60	55	55
55	3	51	86	60	26	26
51	5	55	96	59	35	35
45	6	56	98	59	37	37
39	7	57	95	58	37	37
15	9	60	88	59	37	29
27	10	40	92	59	33	34
21	11	41	91	59	32	33
33	13	44	96	59	29	38
9	14	45	84	59	25	26
3	15	46	80	59	21	21

TABLE IX

VELOCITY SURVEY

Distance Aft of Motor 24.5 ft.

Distance from of Motor	Alcohol Temp.	(inches of Alcohol)	Run Number	Ambient Air Temp.	with rack to of Motor	with rack at 37°	Direction of flow	Speed of flow
inches	°F	inches		°F	#/ft^2	#/ft^2	Degrees	ft/sec
30	65	1.32	98	76	(7.6)*	5.42	2**	69.0
34	69	1.32	83	62	5.4			
35	65	0.95	98	76	(4.7)	3.90	6	64.5
40	69	0.61	83	62	2.5			
40	65	0.35	98	76	(2.5)	1.44	3	46.9
46	69	0.12	83	62	0.49			
45	65	0.14	98	76	(0.70)	0.58	6	24.6
52	69	0.01	83	62	0.04			
49	65	0.07	98	76	(0.10)	0.29	46	9.4

* () Numbers derived from data not in () in this column.

** Degrees are positive when flow is toward of Motor.

TABLE X

VELOCITY SURVEY

Distance Aft of Motor 22 ft.

Distance from of Motor	Alcohol Temp.	(inches of Alcohol)	Run Number	Ambient Air Temp.	with rack to of Motor	with rack at 37°	Direction of flow	Speed of flow
inches	°F	inches		°F	#/ft²	#/ft²	degrees	ft/sec
30	65	1.98	86	64	8.14	(6.6)	-5°	85.3
32	75	1.31	97	86		5.34		
36	65	0.74	86	64	3.04	(1.9)	+2	52.1
38	75	0.29	97	86		1.2		
42	65	0.14	86	64	0.58	(0.60)	22	23.6
44	75	0.10	97	86		0.41		
48	65	0.004	86	64	0.016	(0.05)	46	6.7
50	75	0.003	97	86		0.012		

TABLE XI

VELOCITY SURVEY

Distance Aft of Motor 19 ft.

Distance from of Motor	Alcohol Temp.	(inches of Alcohol)	Run Number	Ambient Air Temp.	with rack to of Motor	with rack at 37°	Direction of flow	Speed of flow
inches	°F	inches		°F	#/ft^2	#/ft^2	degrees	ft/sec
23	66	3.2	90	72	13.18			
23	82	0.63	96			2.56	-11°	221
29	66	1.03	90	72	4.24			
29	82	0.32	96			1.3	-10°	125

TABLE XII

VELOCITY SURVEY

Distance Aft of Motor 16 ft.

Distance from of Motor	Alcohol Temp.	(inches of Alcohol)	Run Number	Ambient Air Temp.	with rack to of Motor	with rack at 37°	Direction of flow	Speed of flow
inches	°F	inches		°F	#/ft^2	#/ft^2	degrees	ft/sec
23	75	2.5	92	89	10.2			
23	82	3.4	95	93		13.8	35°	114
29	75	0.61	92	89	2.5			
29	82	0.84	95	93		3.41	35°	57

FIGURE I

TEST PIT

(Looking toward motor)

FIGURE 2

TEST PIT

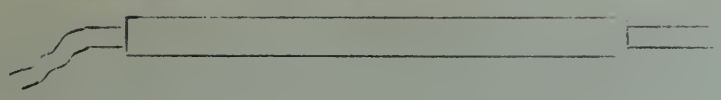
(Looking aft from motor. Rack in right foreground.)

FIGURE 3

CONSTRUCTION OF AN IRON-CONSTANTAN

THERMOCOUPLE

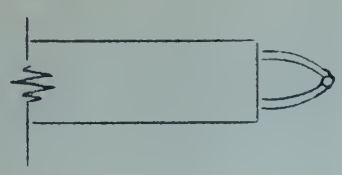
A. Insert wires into porcelain tubing:



B_1. Twist wires as shown in the enlarged diagram and braze, making a small bead of metal which may be blackened with soot.

B_2. Twist the wires as shown but cut so wires cross only once. Silver solder this junction.

C. With either method (B_1 or B_2) the finished thermocouple will be as follows:



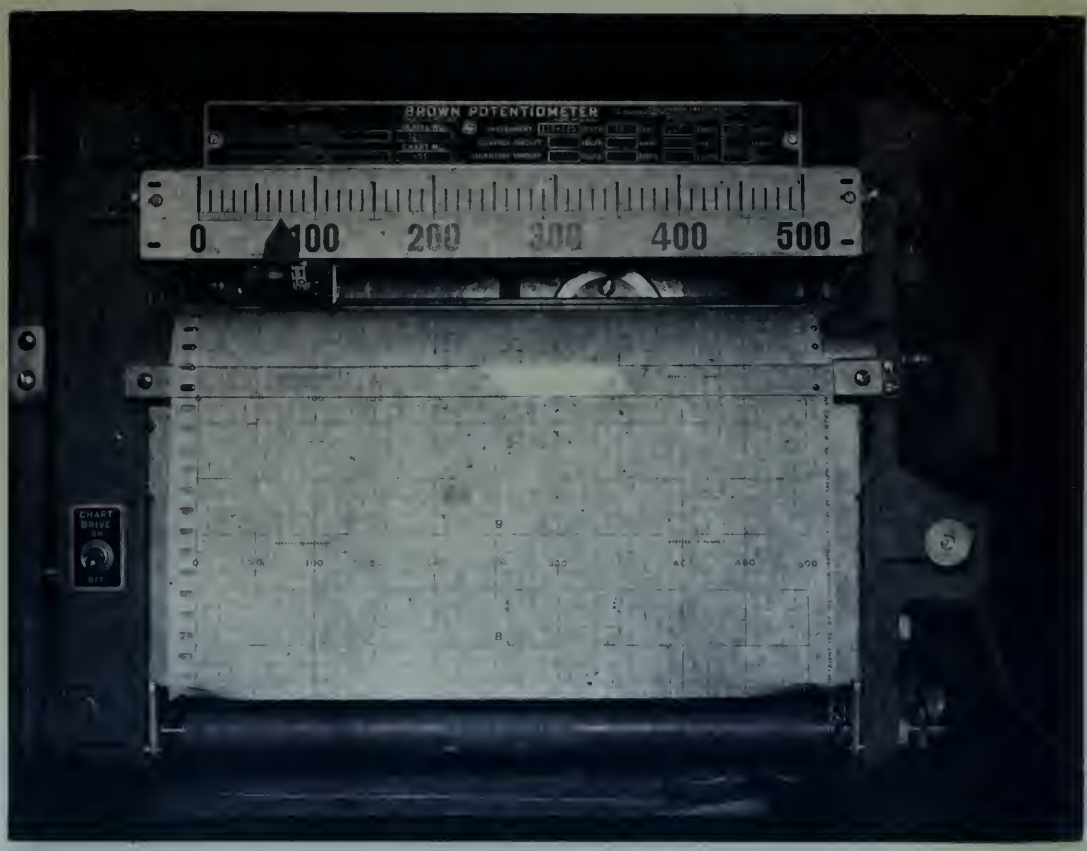


FIGURE 4

BROWN POTENTIOMETER

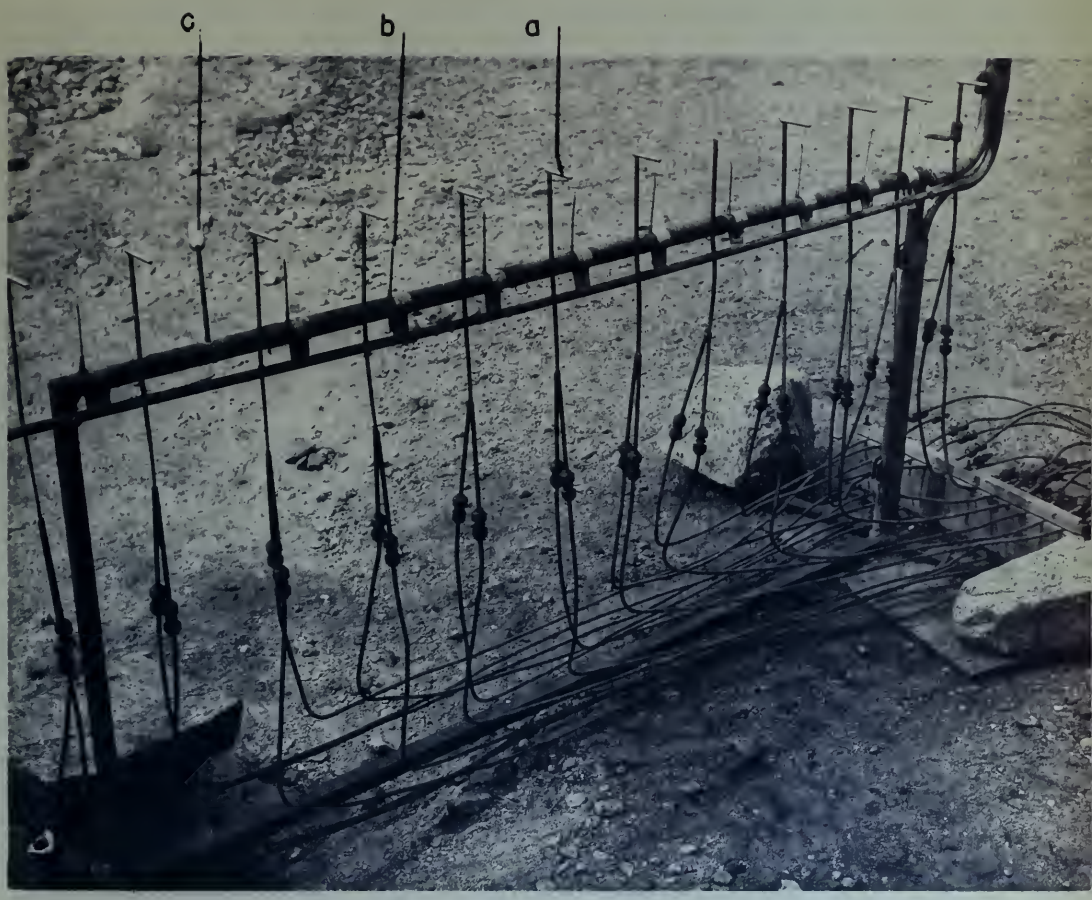


FIGURE 5

RACK

(a) Prandtl Pitot tube

(b) Thermocouple

(c) Stagnation temperature probe

FIGURE 6

SHIELDED THERMOCOUPLE

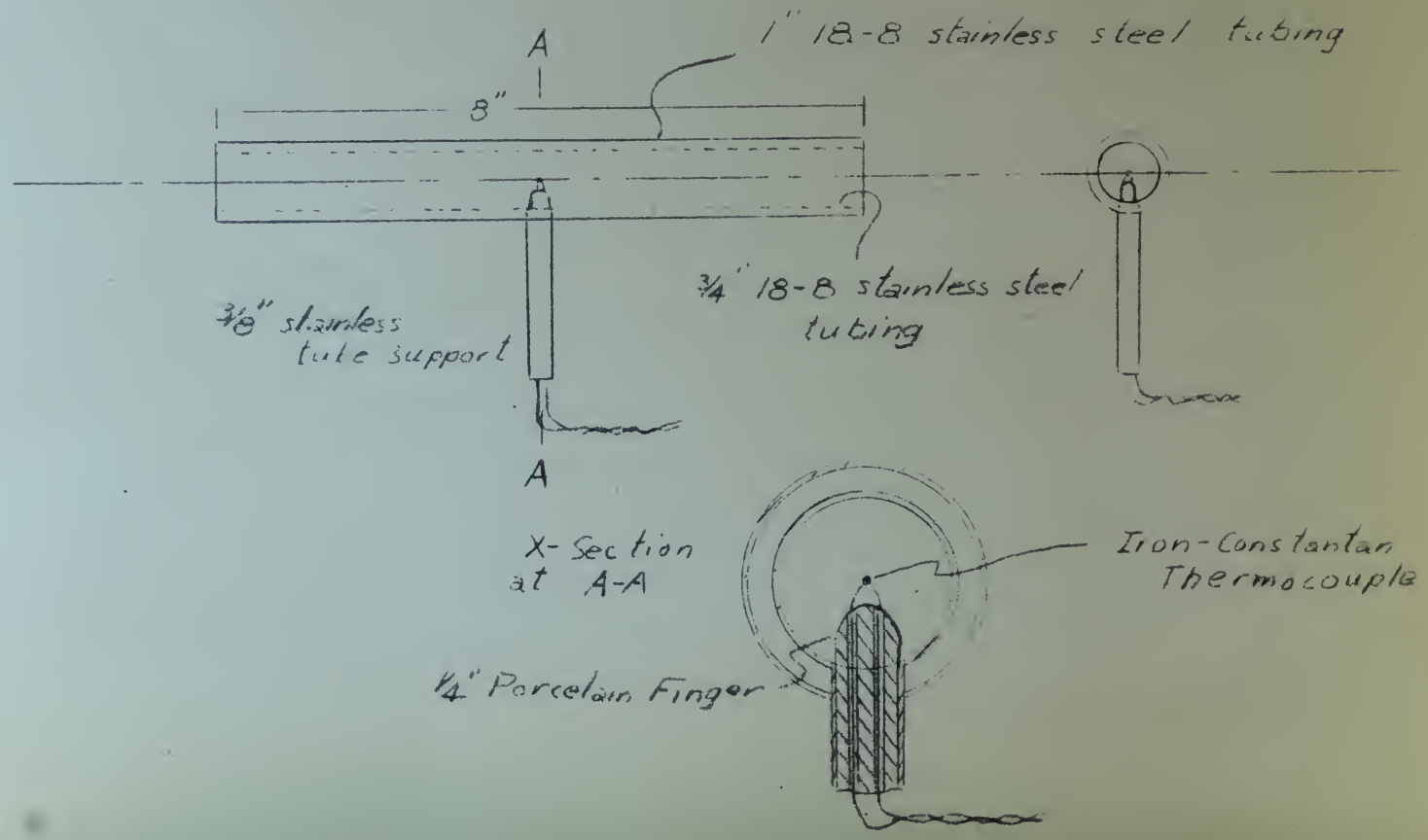
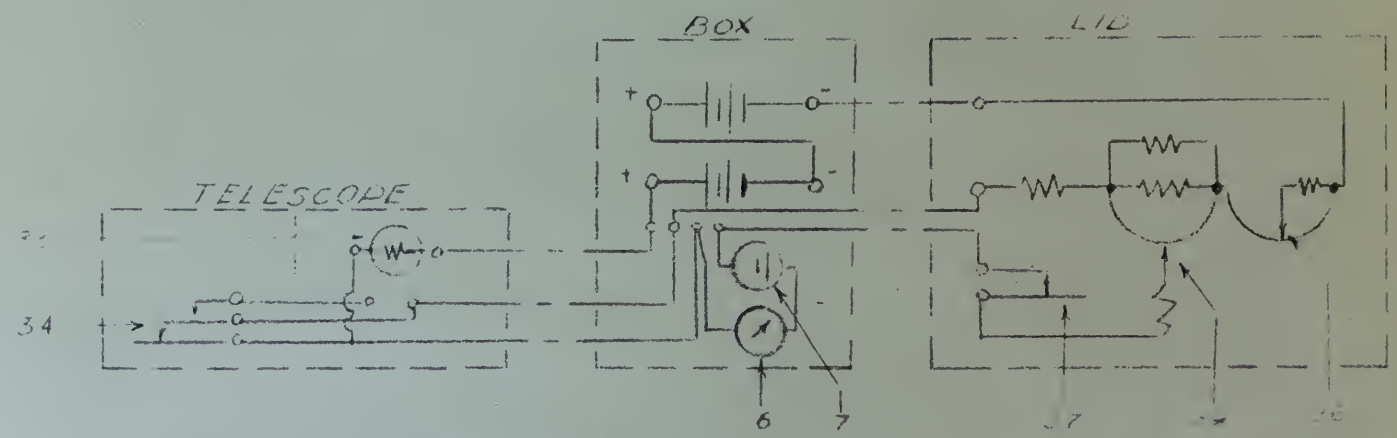


Figure 7

OPTICAL PYROMETER CIRCUIT



6 - Galvanometer

7 - Standard Cell

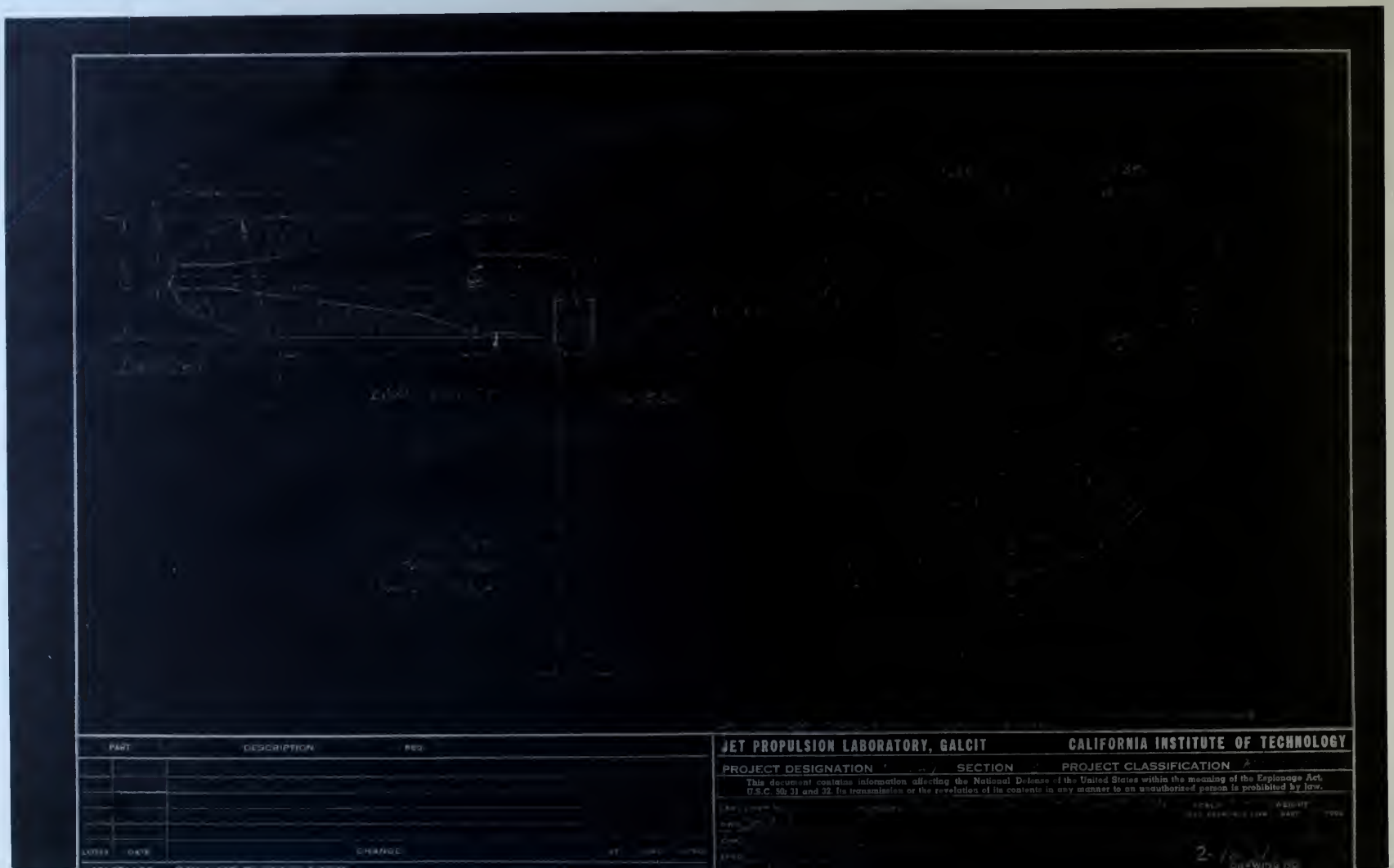
33 - Lamp

34 - Switch

37 - Switch

36 - 39 - Slide Wire Resistance

FIGURE 8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BY
JET PROPULSION LABORATORY, GALCIT
CALIFORNIA INSTITUTE OF TECHNOLOGY
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SECTION
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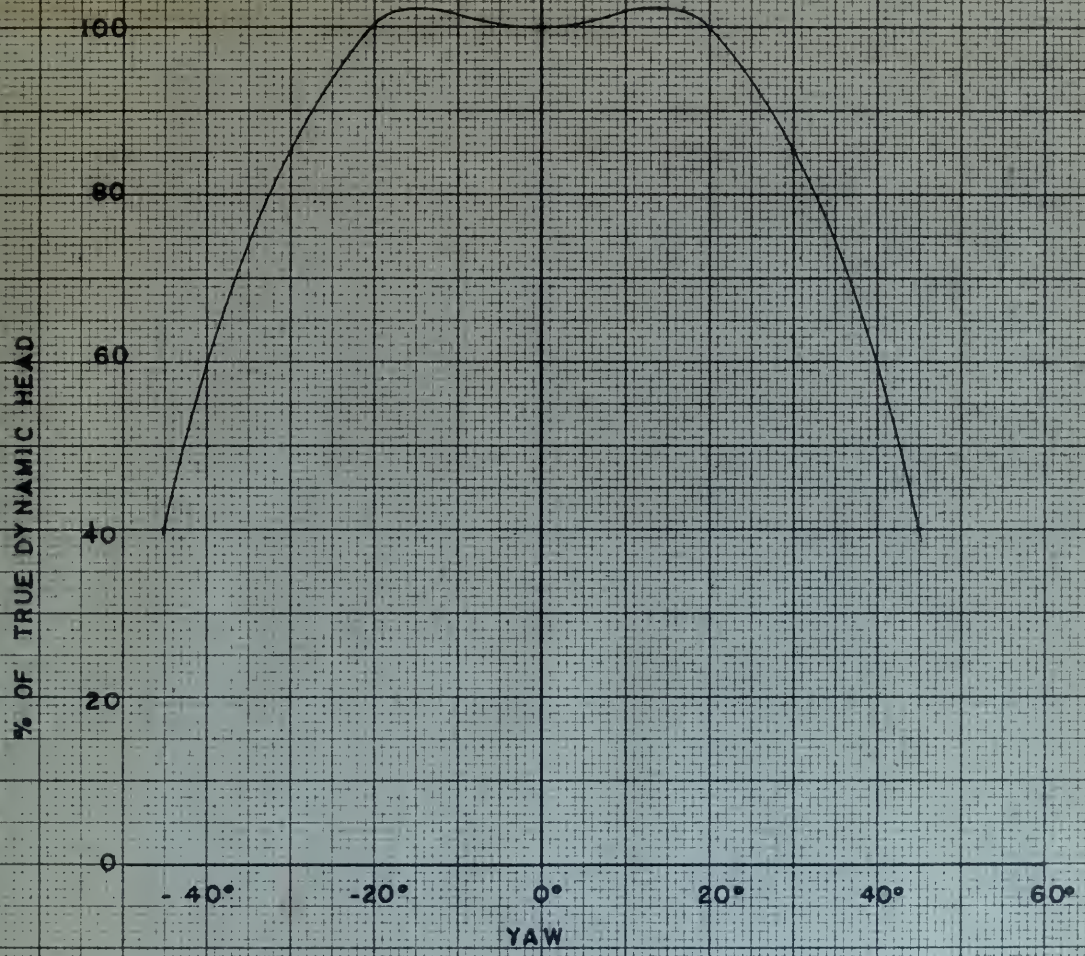
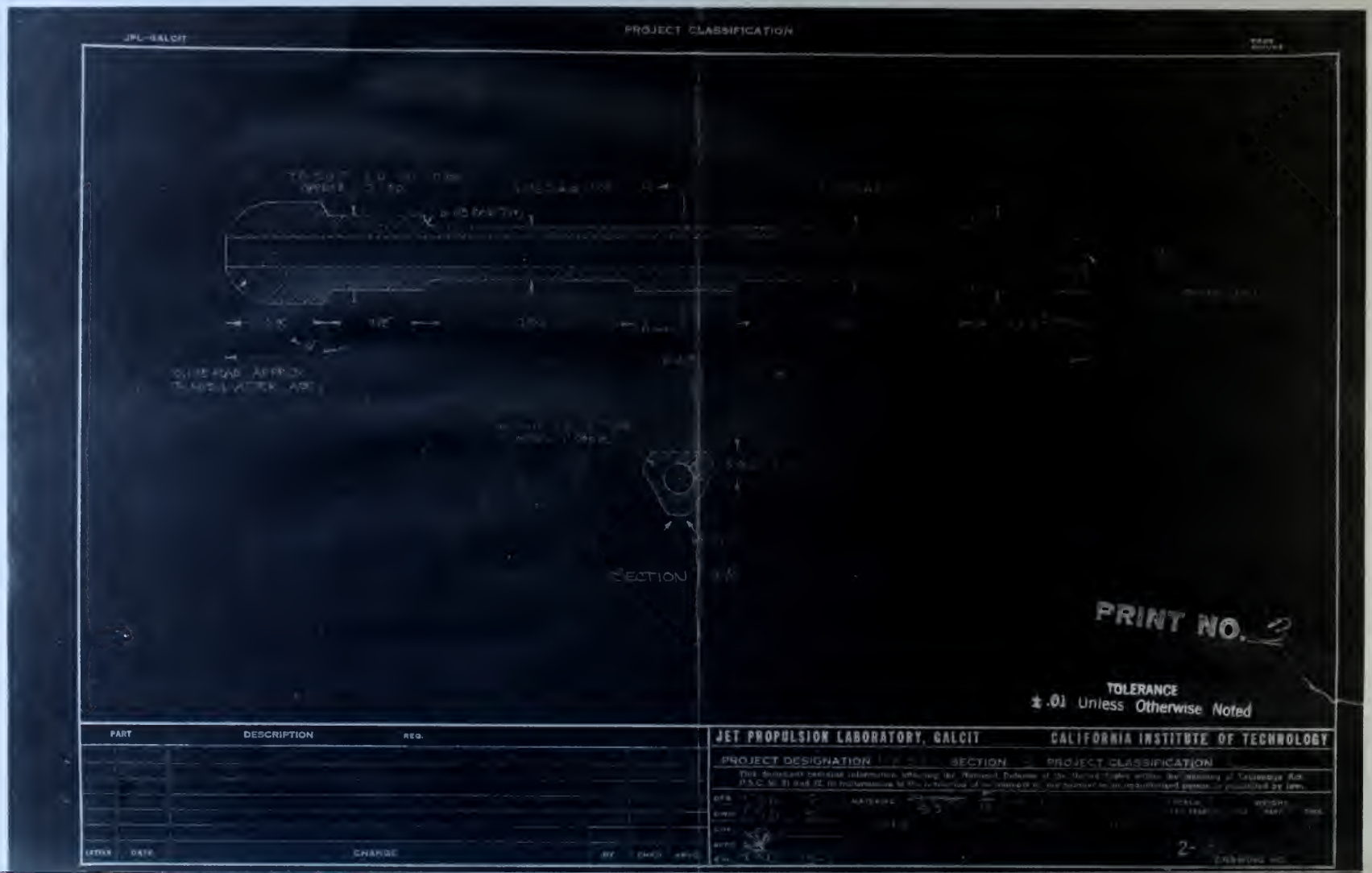


FIGURE 9

YAW CHARACTERISTICS OF PRANDTLE TUBE

FIGURE 10a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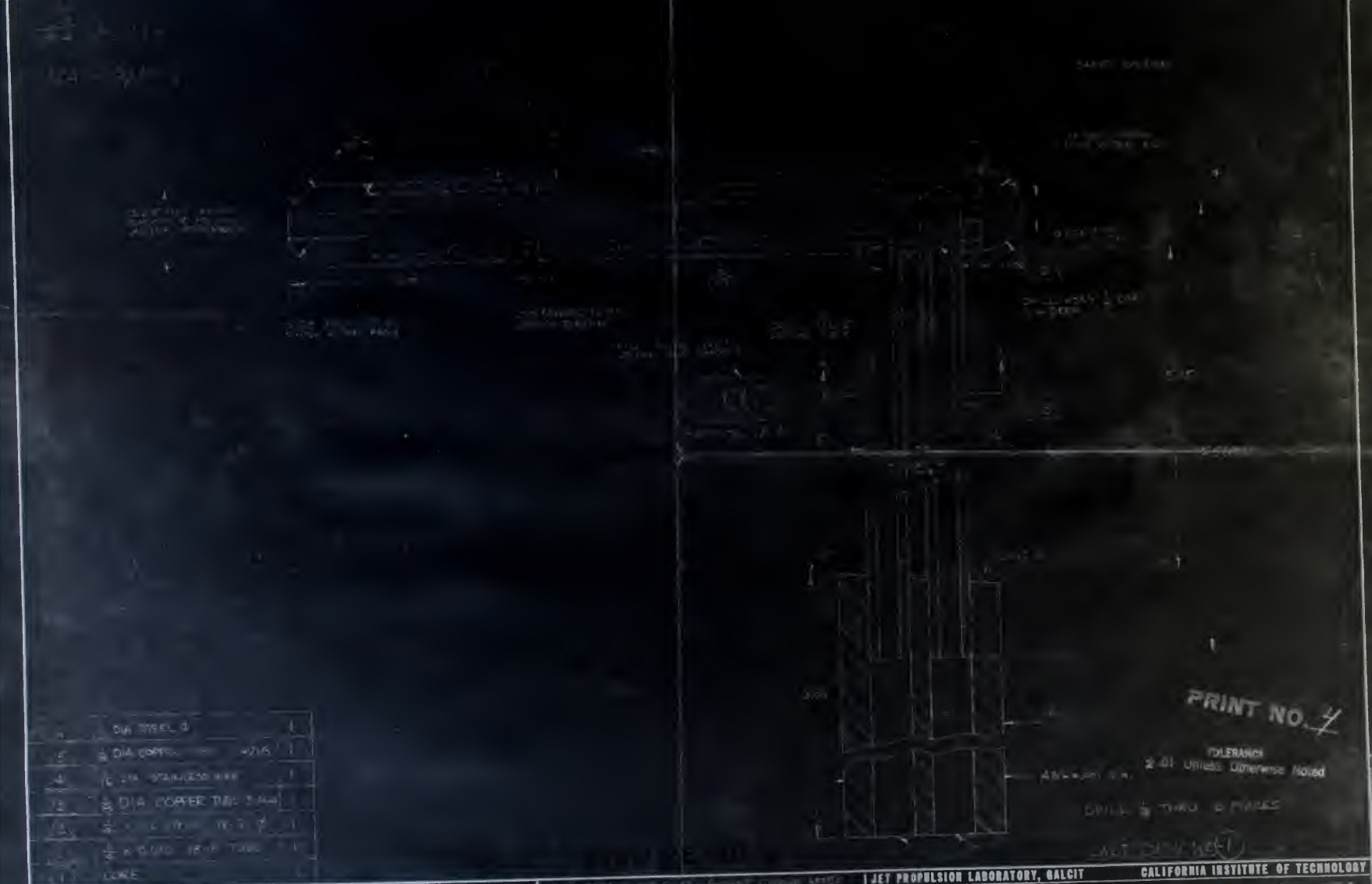
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SECTION
PROJECT CLASSIFICATION
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WEIGHT
4-360
DRAWING NO.

FIGURE 11

TILTING MULTIPLE MANOMETER
(in the 14.5° position)

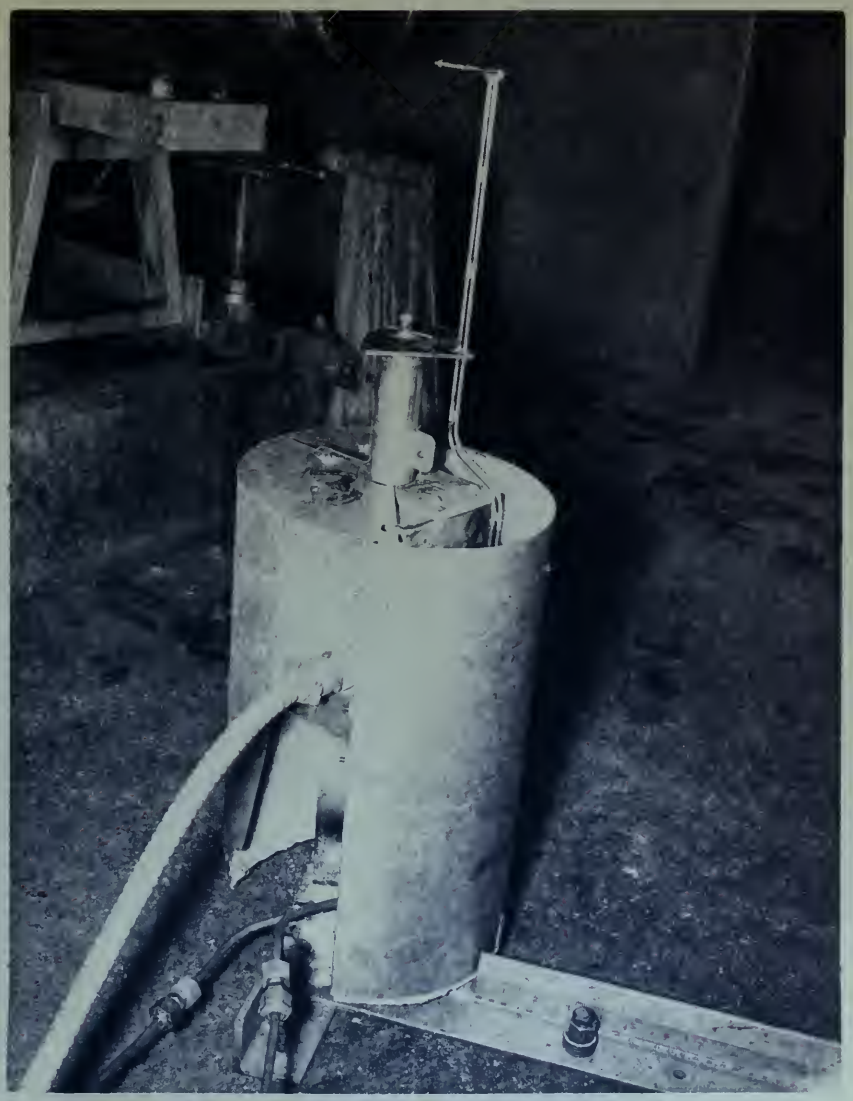


FIGURE 12

REMOTE CONTROLLED PITOT TUBE
(Assembled)

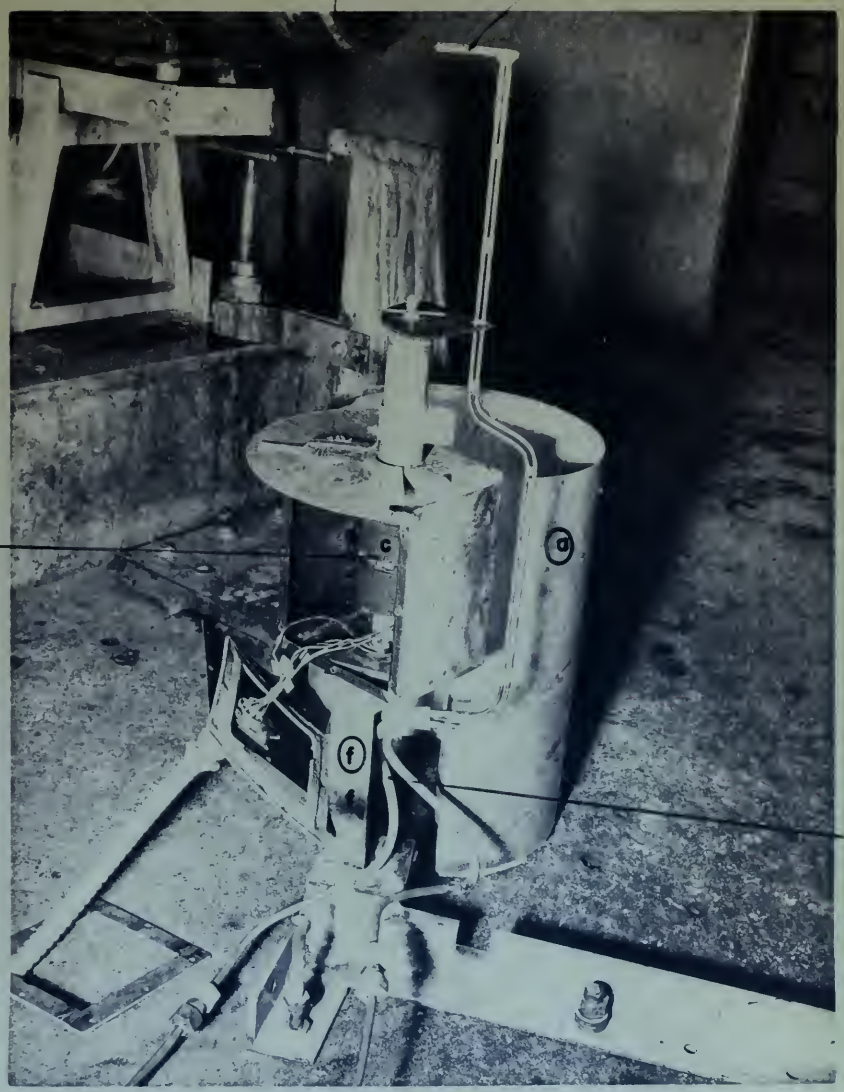


FIGURE 13

REMOTE CONTROLLED PITOT TUBE
(Disassembled)

(a) Aluminum shield
(b) Rubber tubes
(c) Synchro
(d) Pitot tube
(e) Motor
(f) Adjustable support

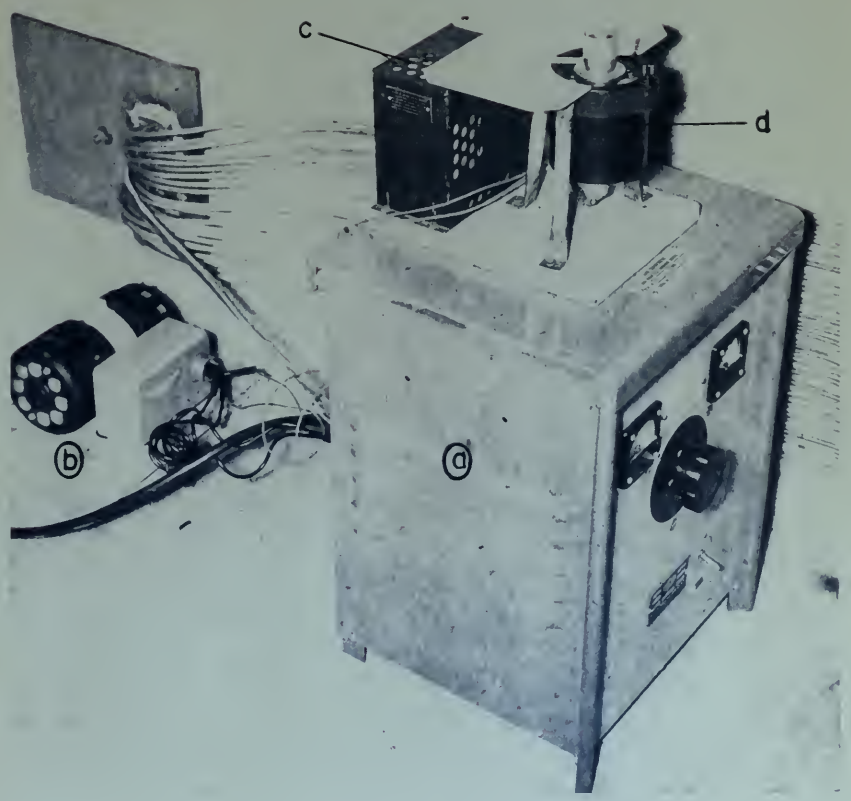


FIGURE 14

SYNCHRO CONTROL

a Rectifier (220 a.c. to 24 d.c.)

b Inverter (24 d.c. to 110 a.c. 400 ~)

c Amplifier

d Synchro

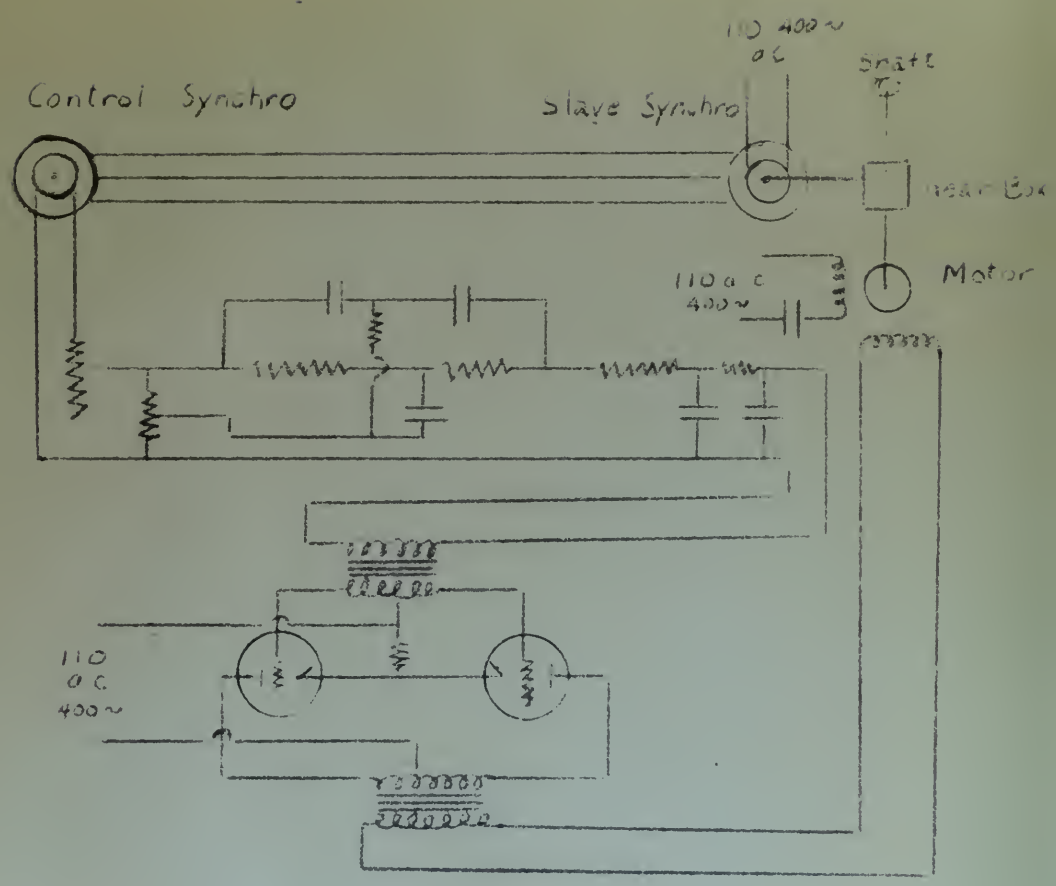


FIGURE 15

Electrical Circuit For The Remote Controlled Pitot-Static Tube

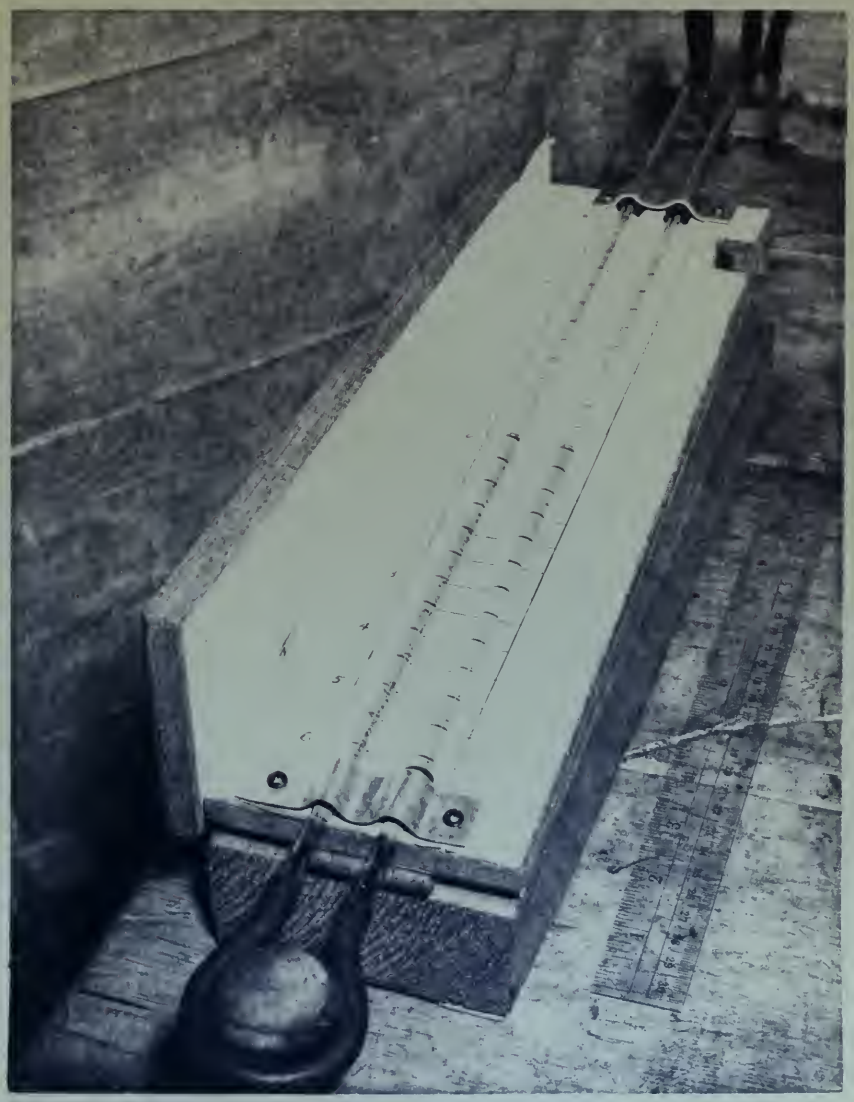


FIGURE 16

SMALL INCLINED MANOMETER

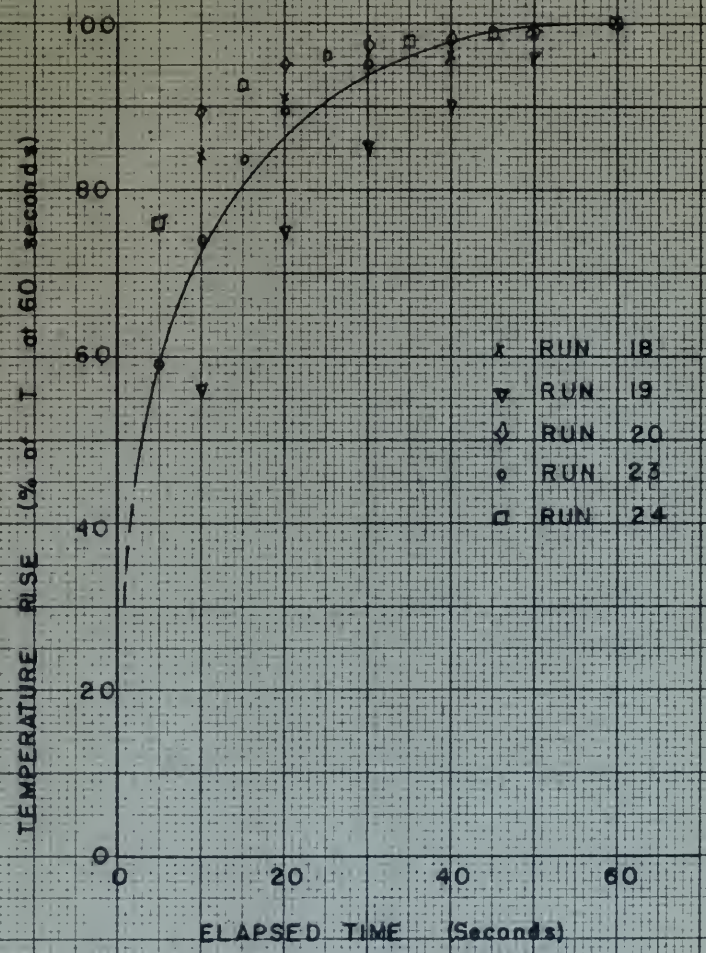


FIGURE 17

THERMOCOUPLE TEMPERATURE RESPONSE

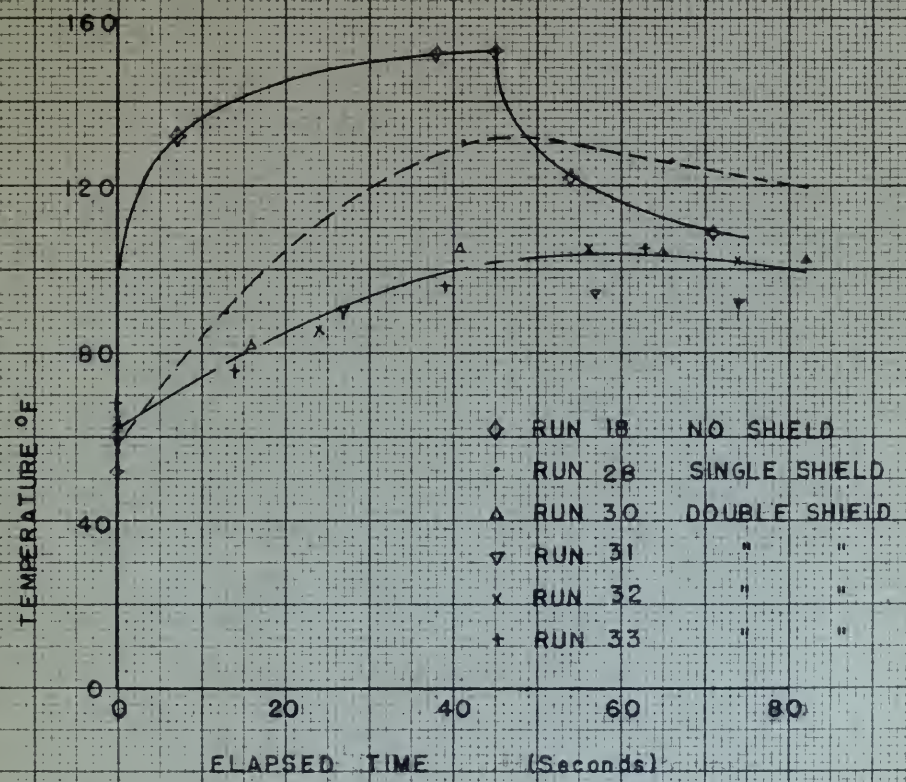


FIGURE 18

SHIELDED THERMOCOUPLE RESPONSE

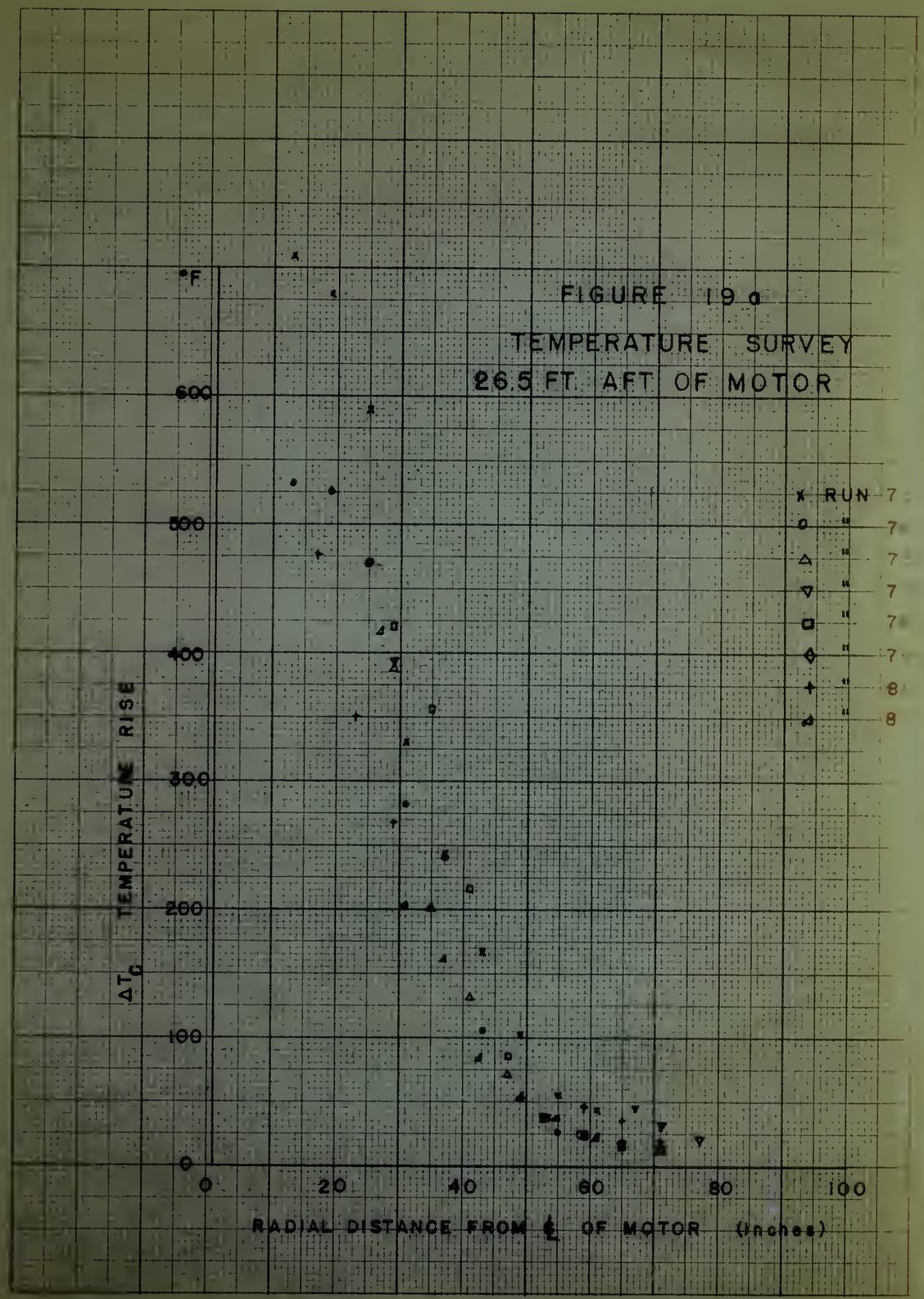


FIGURE 19 a
TEMPERATURE SURVEY
26.5 FT. AFT OF MOTOR

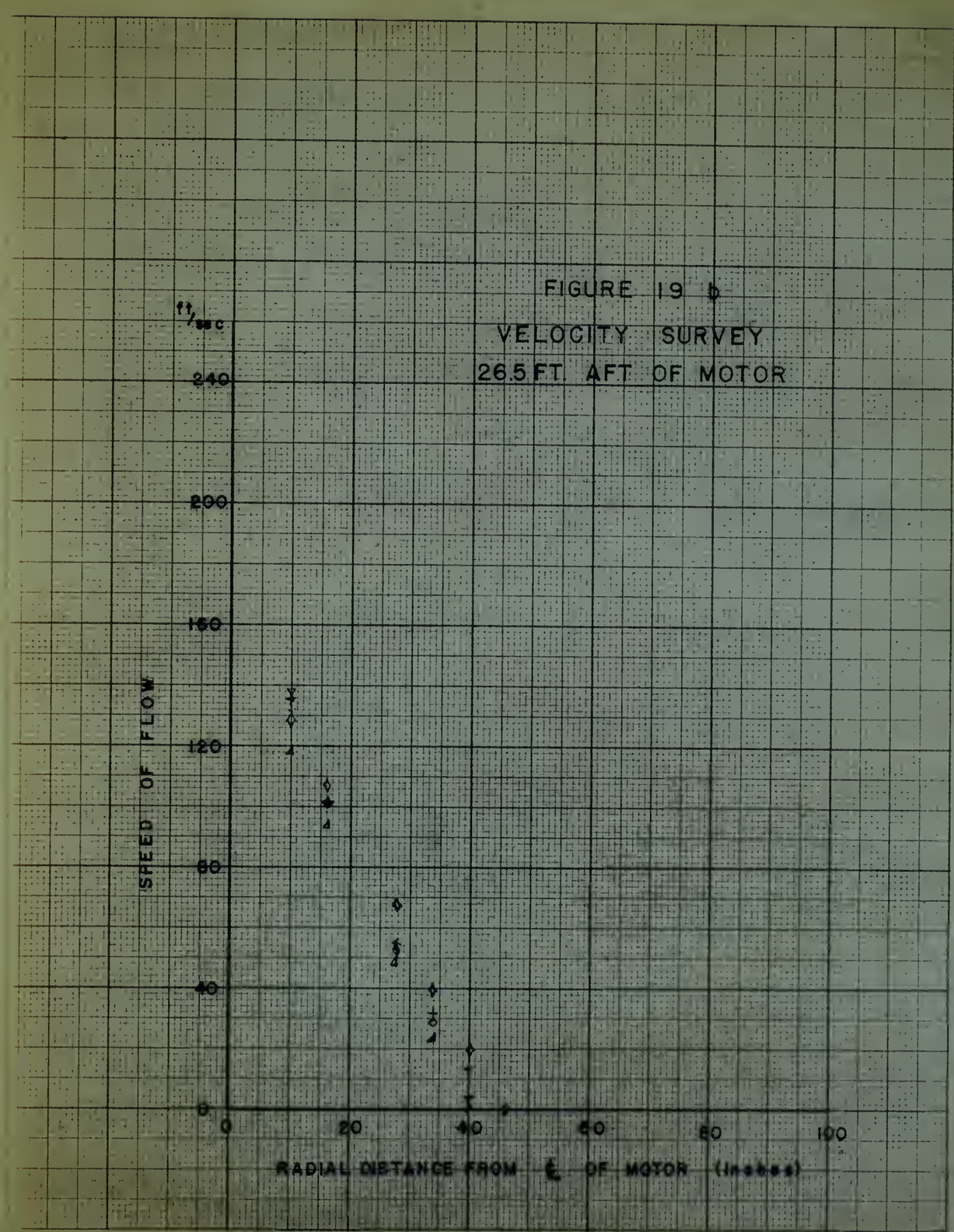


FIGURE 19 b
VELOCITY SURVEY
26.5 FT. AFT OF MOTOR

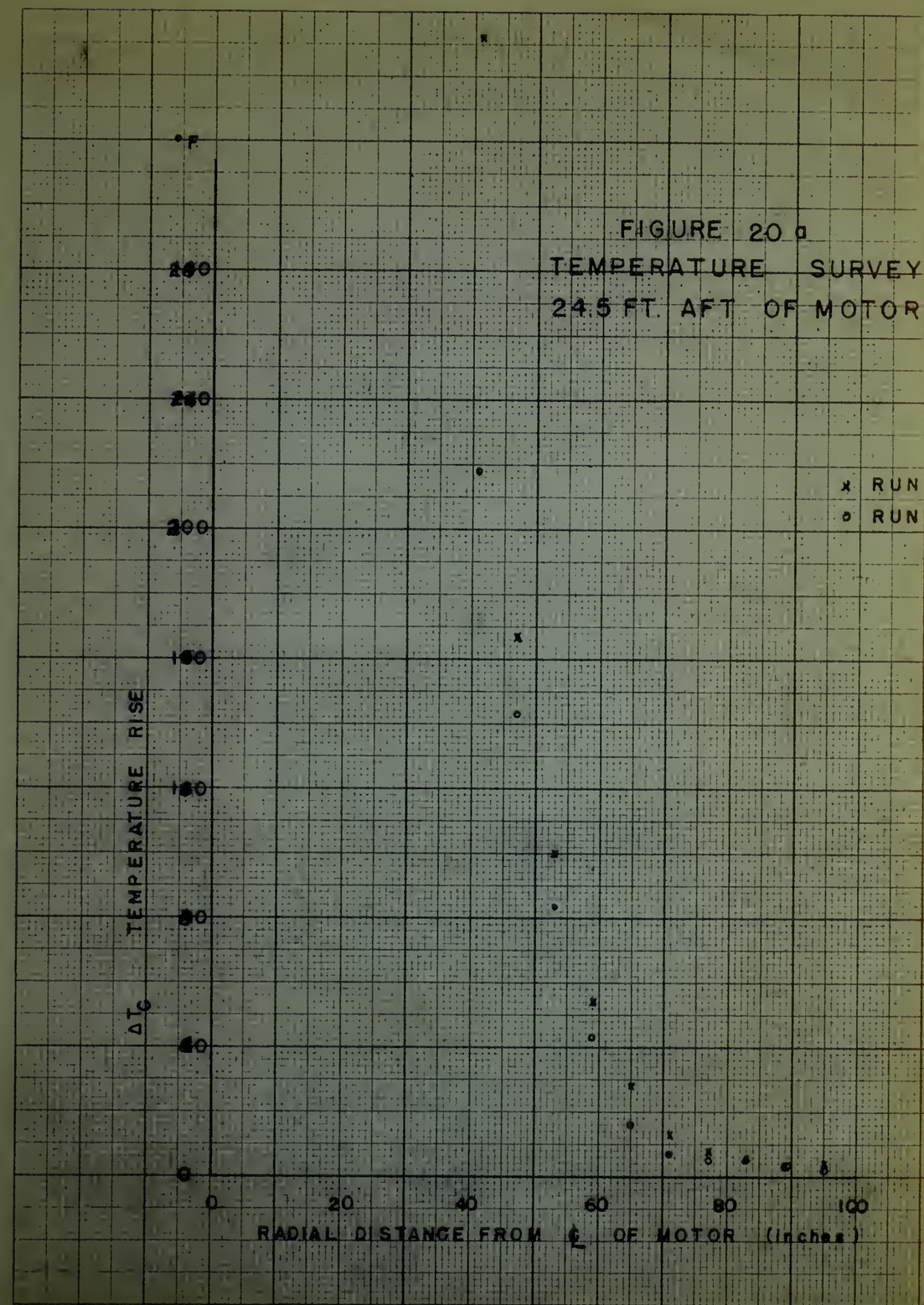


FIGURE 20a
TEMPERATURE SURVEY
24.5 FT. AFT OF MOTOR

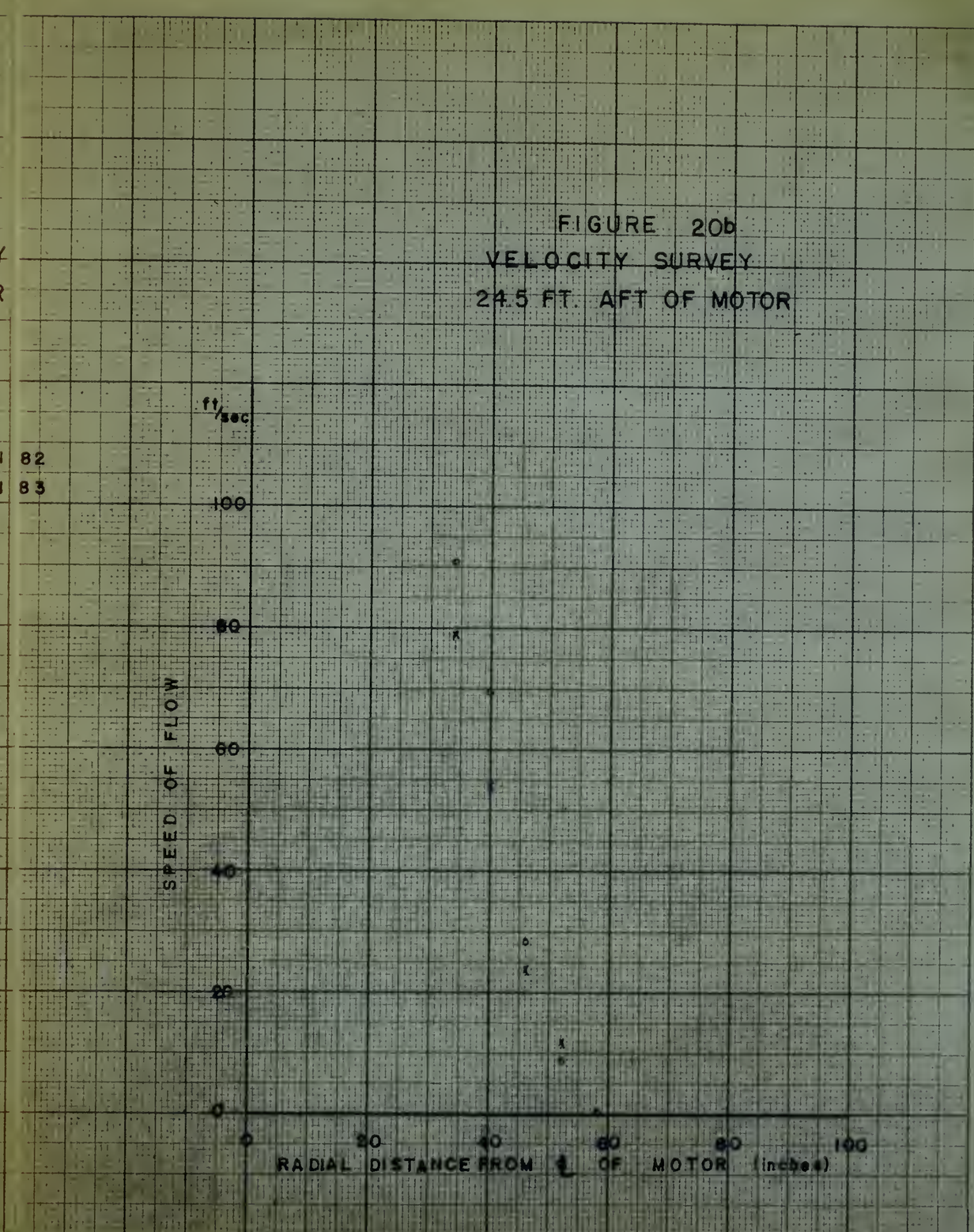


FIGURE 20b
VELOCITY SURVEY
24.5 FT. AFT OF MOTOR

FIGURE 21a

TEMPERATURE SURVEY

22FT. AFT OF MOTOR

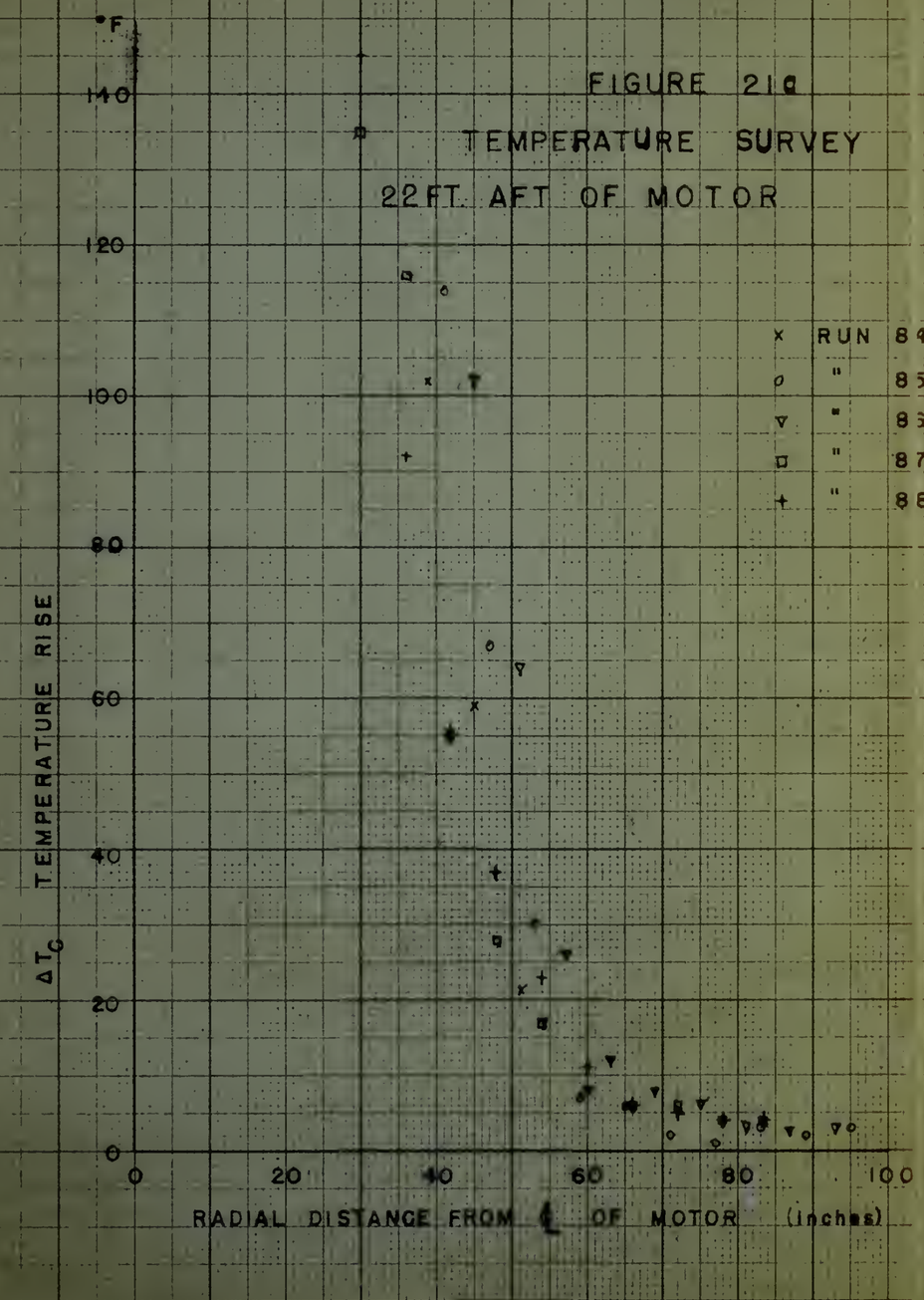
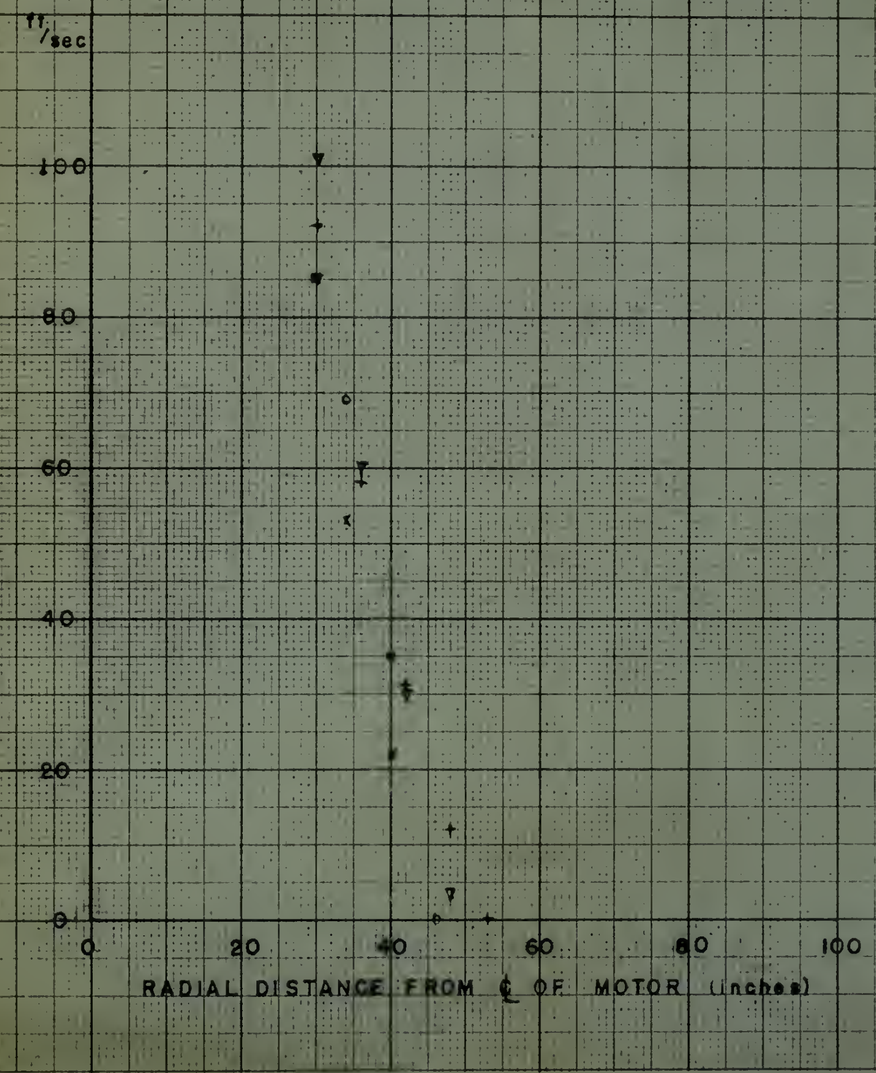


FIGURE 21b

VELOCITY SURVEY

22FT. AFT OF MOTOR



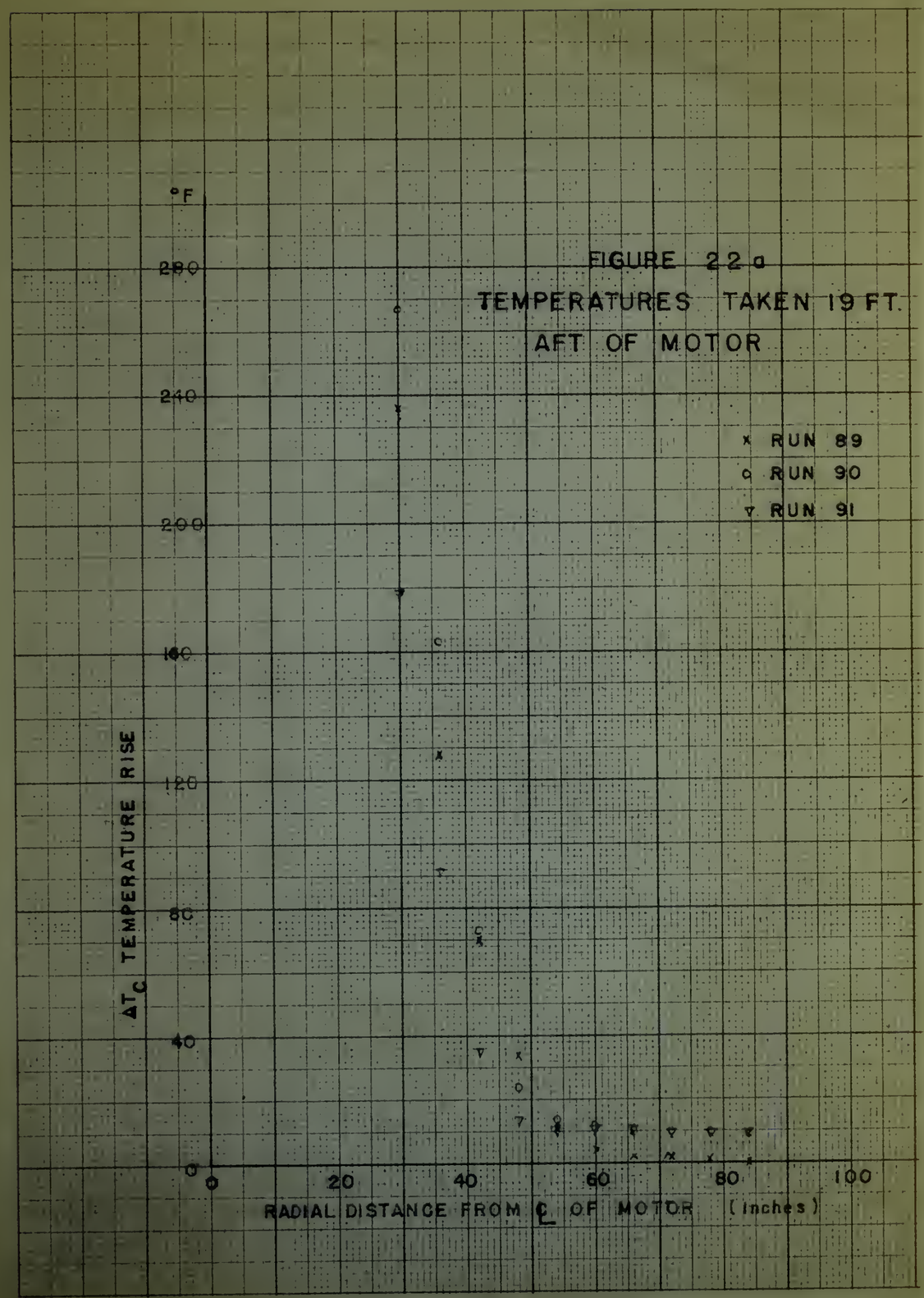


FIGURE 22a
TEMPERATURES TAKEN 19 FT.
AFT OF MOTOR

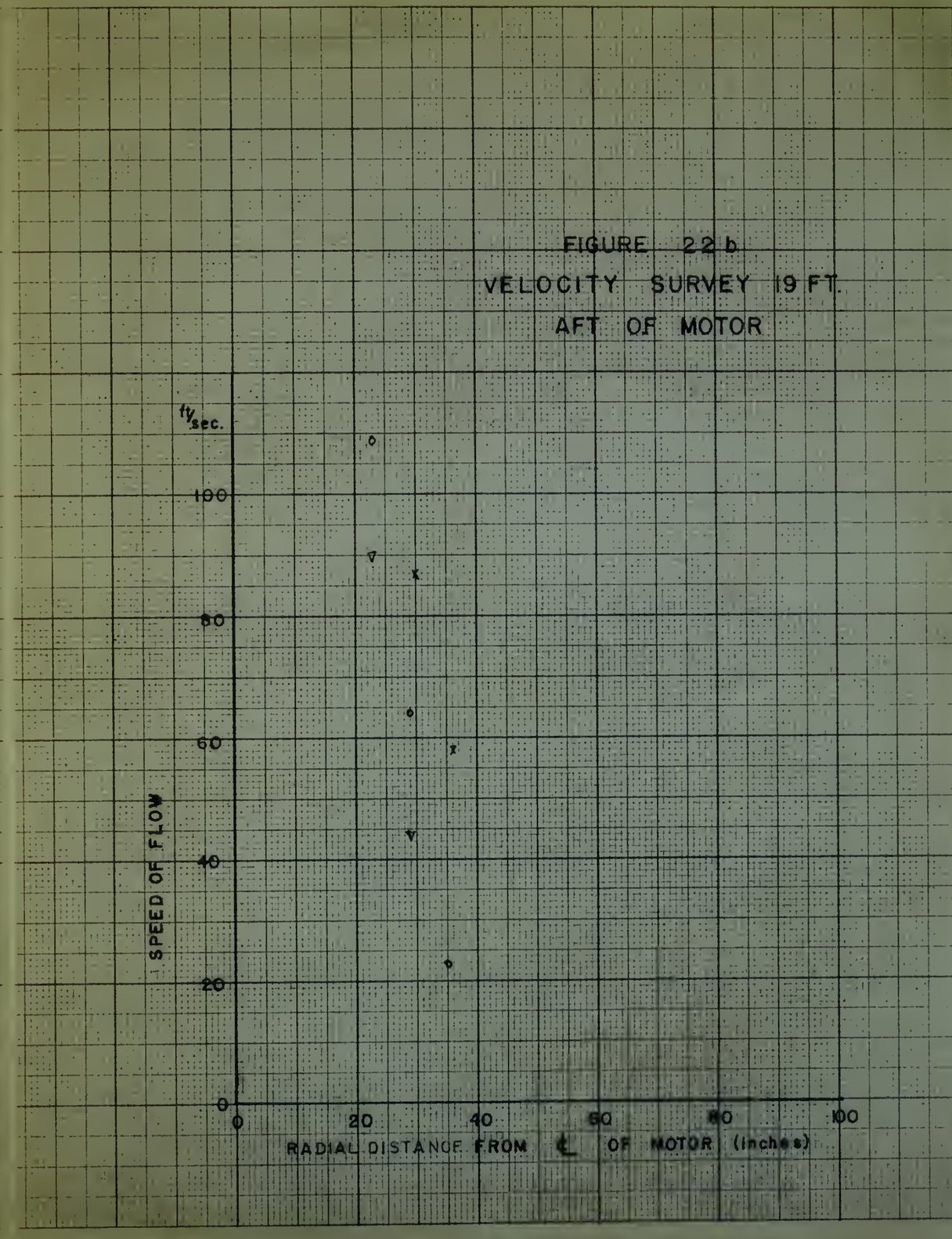


FIGURE 22b
VELOCITY SURVEY 19 FT.
AFT OF MOTOR

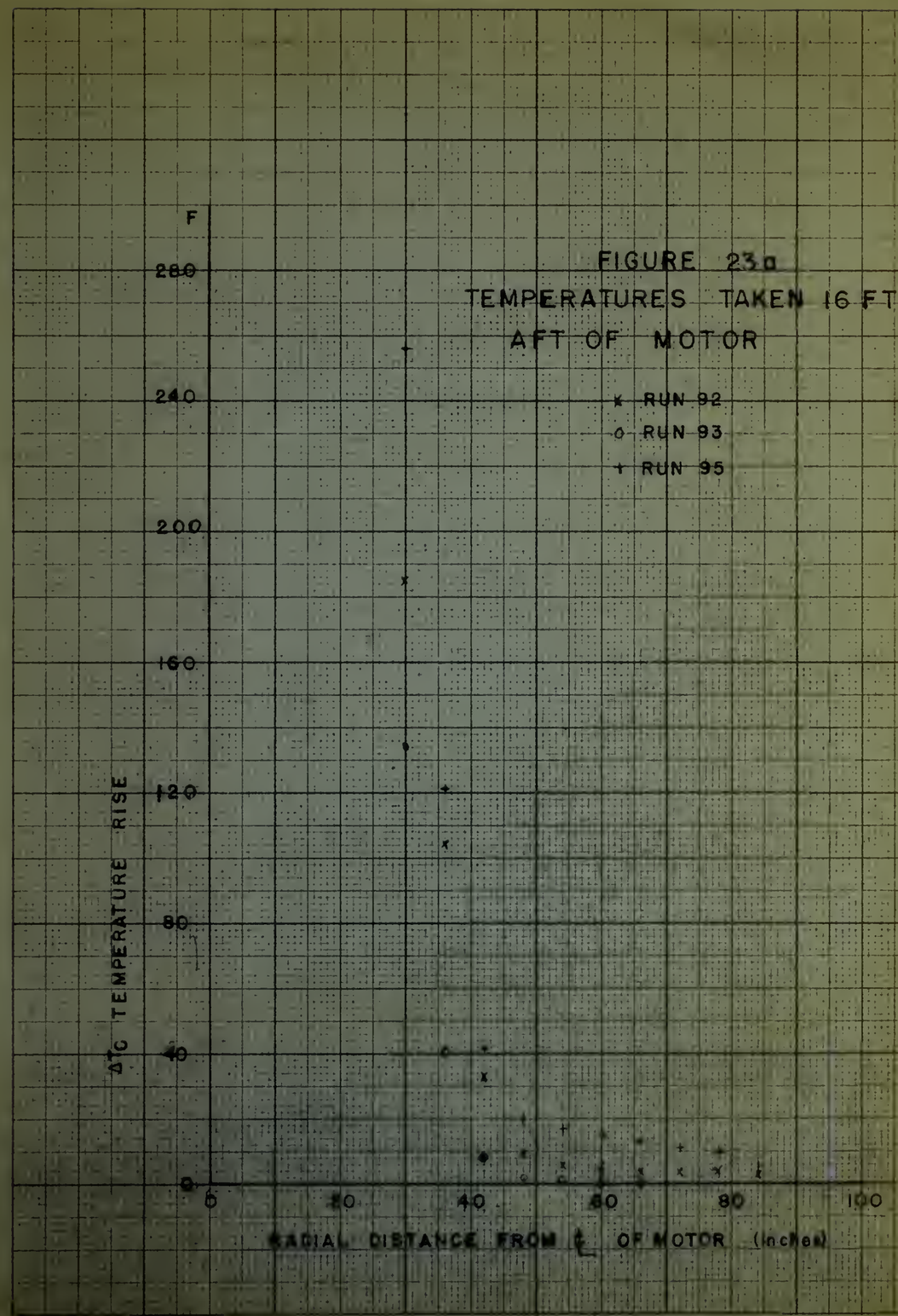


FIGURE 23a
TEMPERATURES TAKEN 16 FT.
AFT OF MOTOR

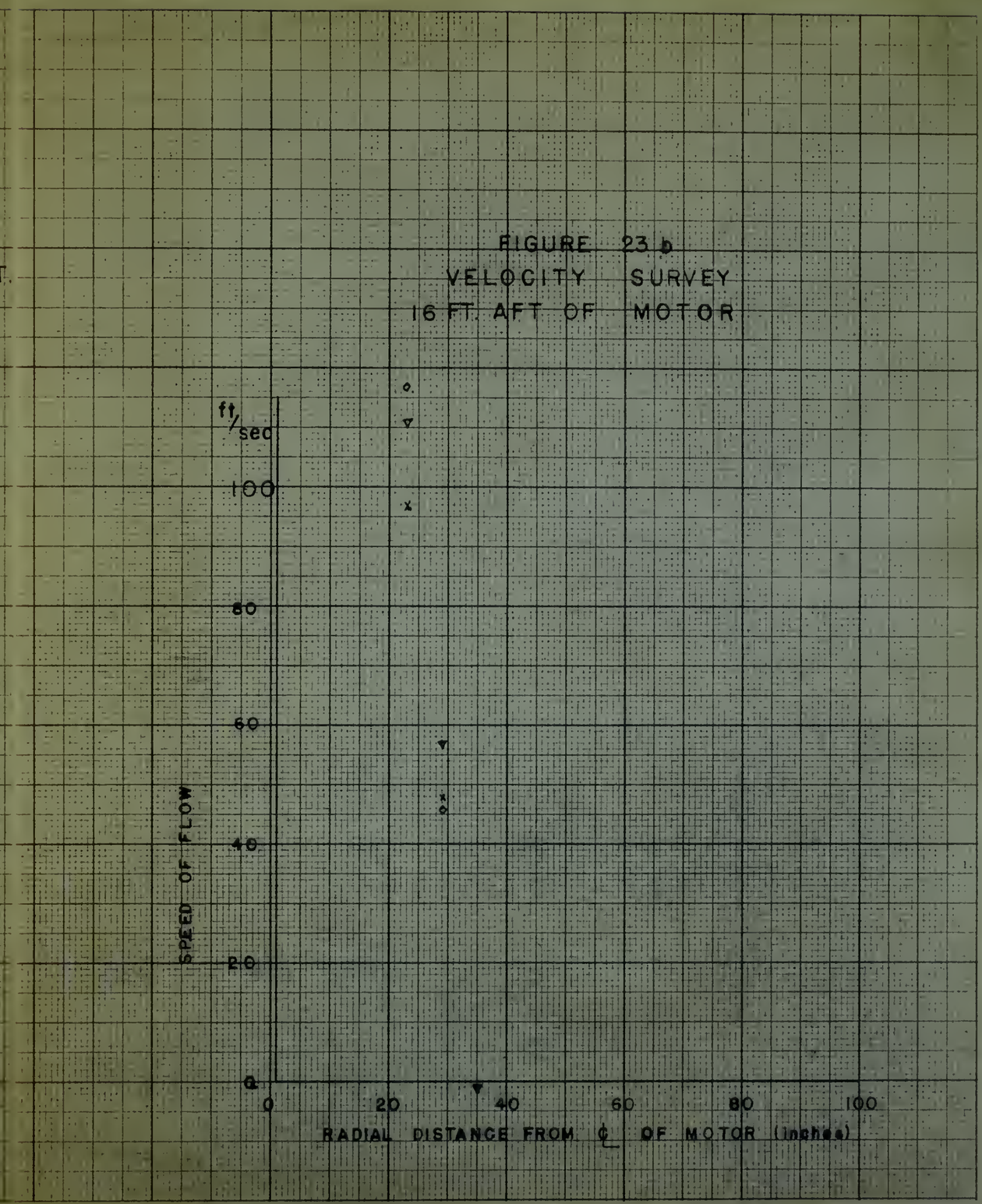


FIGURE 23b
VELOCITY SURVEY
16 FT. AFT OF MOTOR

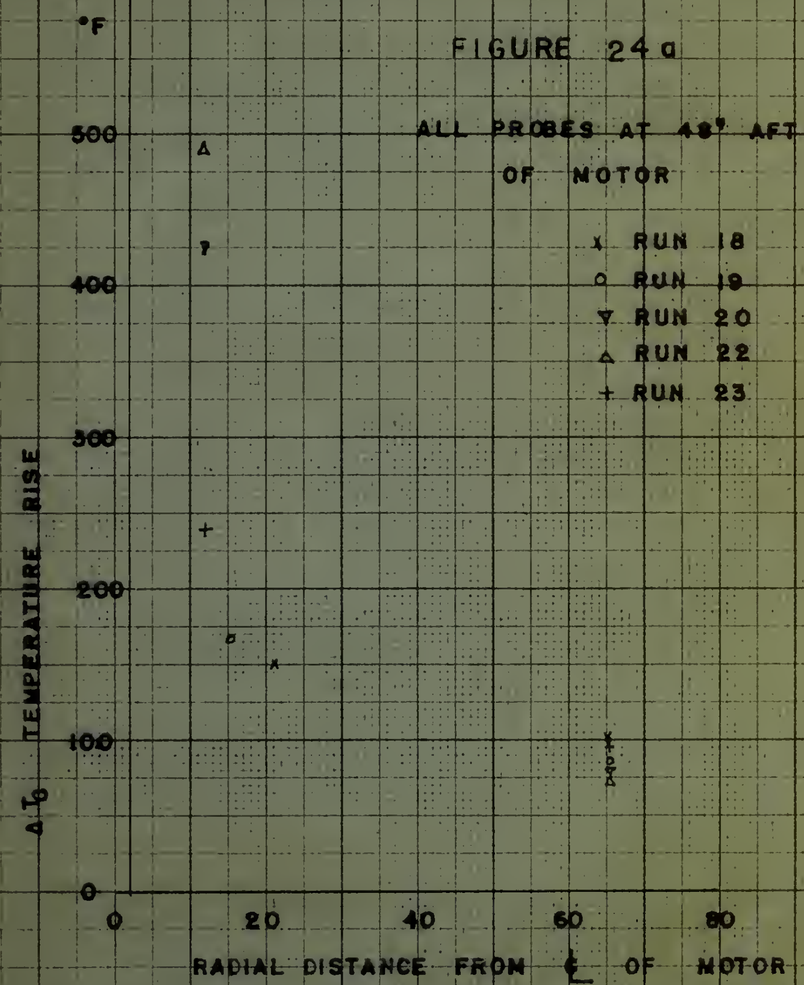


FIGURE 24 a

ALL PROBES AT 48" AFT OF MOTOR

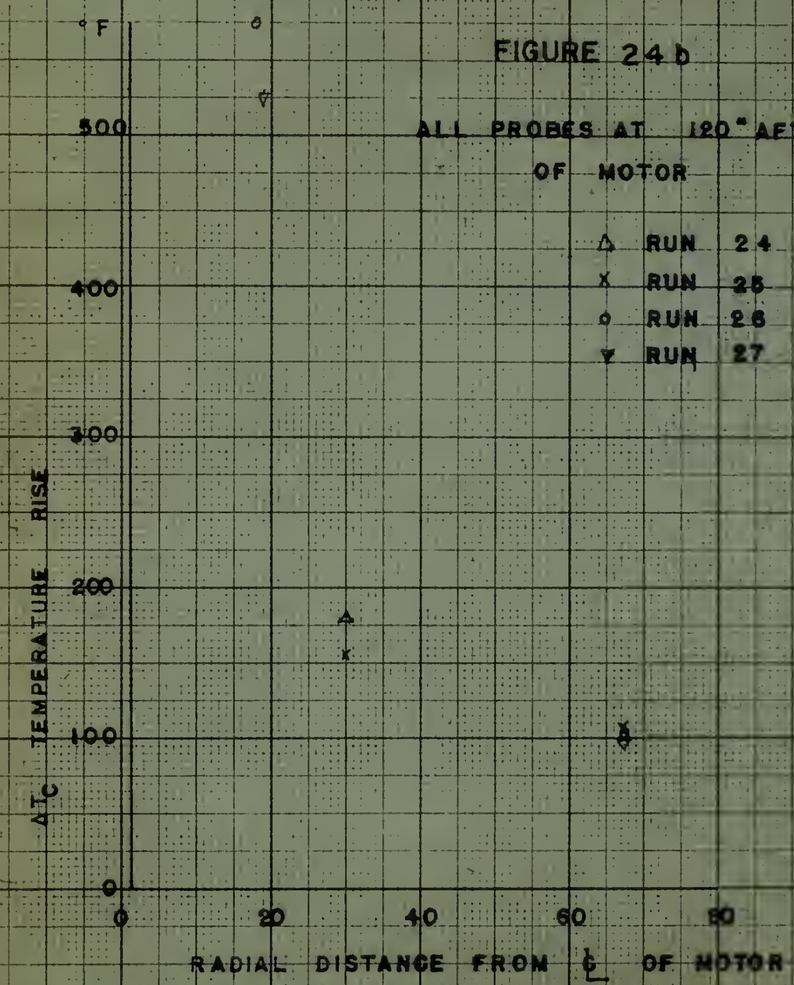


FIGURE 24 b

ALL PROBES AT 120" AFT OF MOTOR

FIGURE 25

VELOCITY SURVEY

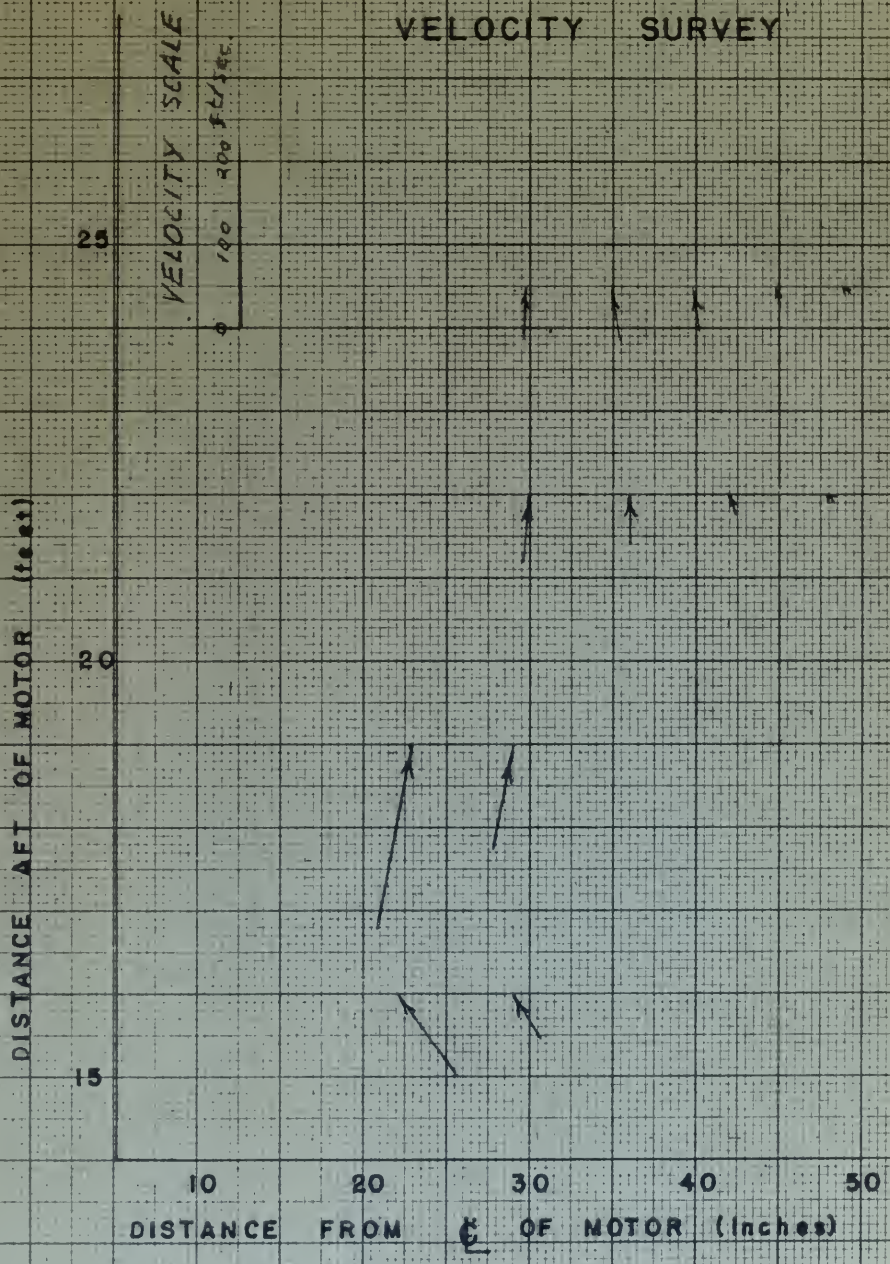
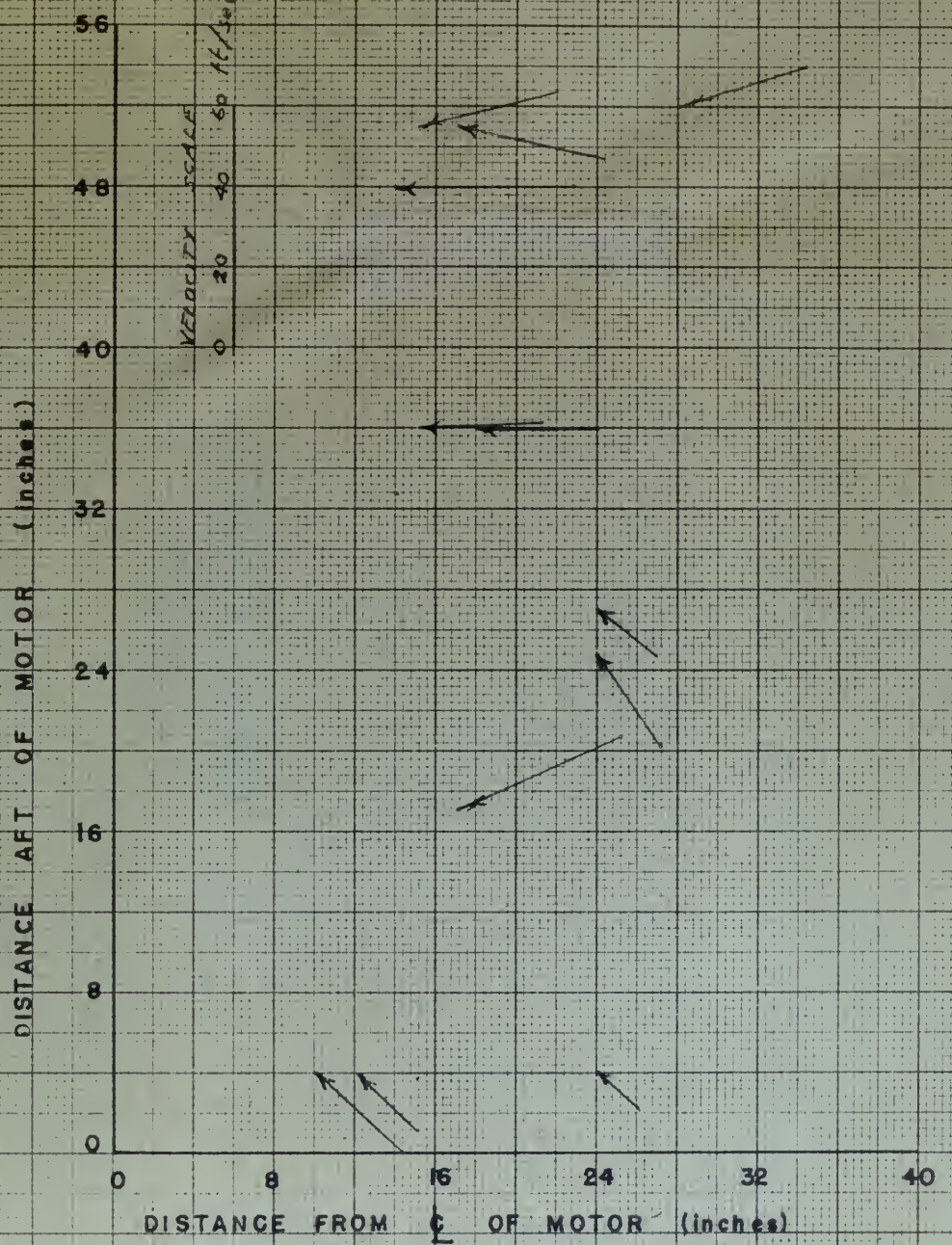


FIGURE 26

VELOCITY SURVEY



DATE DUE

Thesis 8104
W56 Whitmore
Experimental investigation of temperature and velocity distribution about a rocket jet.